NUTHOS-12

Integral SMART Plant Model Development using the System Thermal-Hydraulic Code TRACE for Transient Analysis

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Content

- Motivation
- Main peculiarities of the SMART plant
- The system thermal hydraulic code TRACE
- Approach followed for the development of the integral TRACE model
- Short description of the integral model
- Stationary plant conditions predicted by TRACE
- Summary
- Outlook

Motivation

- Global trend for exergy generation in small units ➡ Small Modular Reactors (SMR)
  - Short construction time & low investment cost
  - Operational flexibility within versatile grid architectures
  - Remote location
  - Cogeneration capability (electricity and water desalination)

- Various SMR concepts worldwide under construction and development
  - Light water cooled (CAREM, SMART, KLT-40S, CNP300, NuSCALE, ACPR50S)
  - Helium cooled (HTR-PM)
  - Liquid metal cooled SMR (PRISM, BREST, SVBR-100, ARC-100)

Superior SMR Feature compared to large Units

- Safety concept of innovative SMR-designs relying on **passive SAFETY**
  - Exclusion of some accident initiators (e.g. Large break LOCA).
  - Heat removal (short & long term) natural circulation based plus passive heat removal
  - Limited power provides options for infinite heat sinks ("walk-away reactor"?)

➡ Demonstration of **passive safety performance pre-requisite for licensing**

This talk:
❑ Evaluation of the SMART-behaviour at steady state conditions

KIT Approach to Evaluate the SMART-Plant

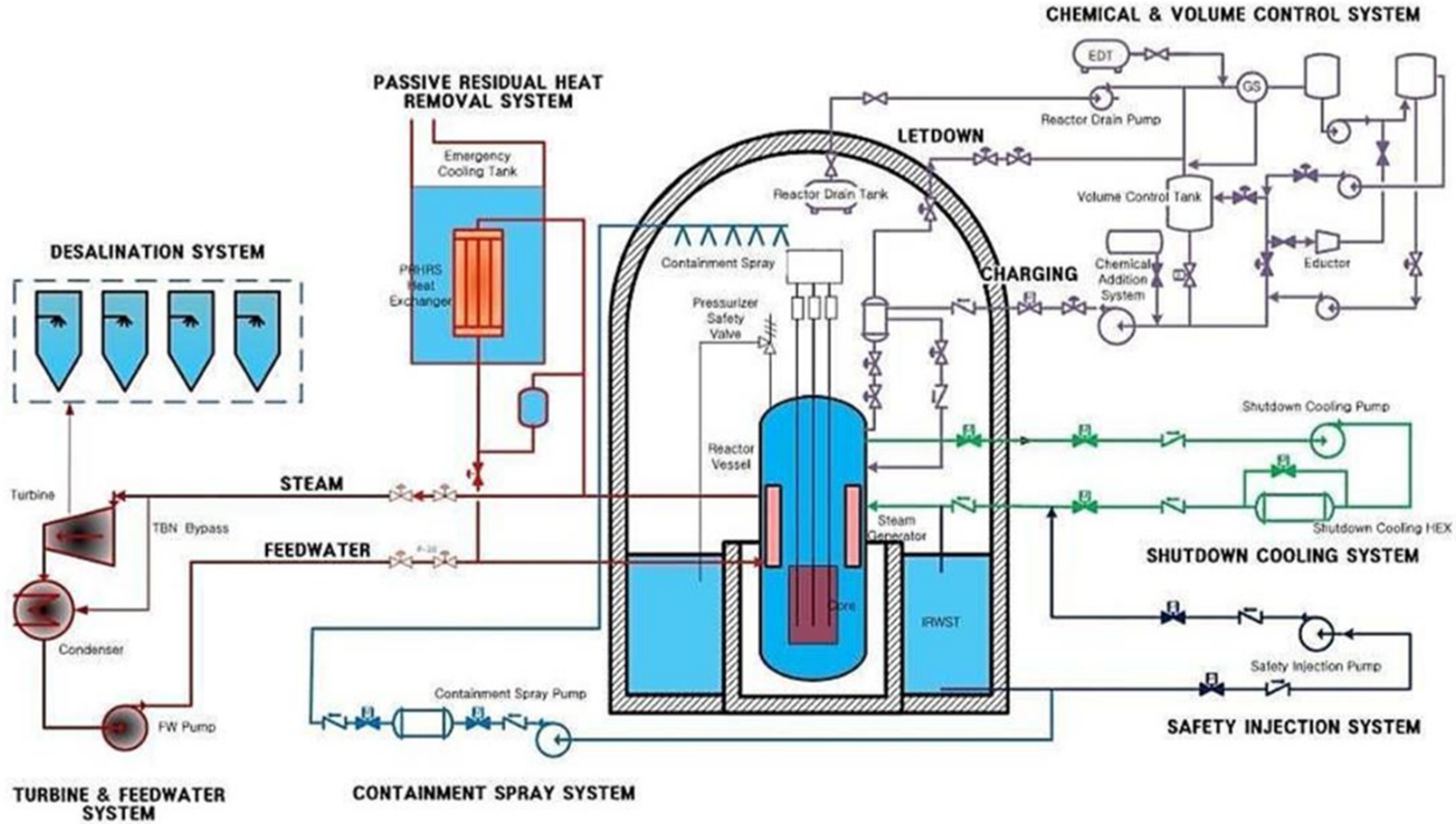
Consecutive approach to analyze SMART

- **Task-1**: Development of an integral plant model for a system thermal hydraulic code e.g. TRACE
  - Simulation of plant stationary conditions
  - Extend the model for analysis of the plant under transient conditions
- **Task-2**: Analysis of safety relevant transients by coupled 3D N/TH codes

- Steps required for **Task-1**:
  - Collection of public available data about SMART
    - Geometry, materials, operation conditions
    - Neutronic data, thermo-physical data of key-materials
    - Representation of safety systems
    - Integration of Containment Model

AIM:
independent development of integral SMART model (for TRACE analysis) based on public data

Peculiarities of the SMR SMART Plant

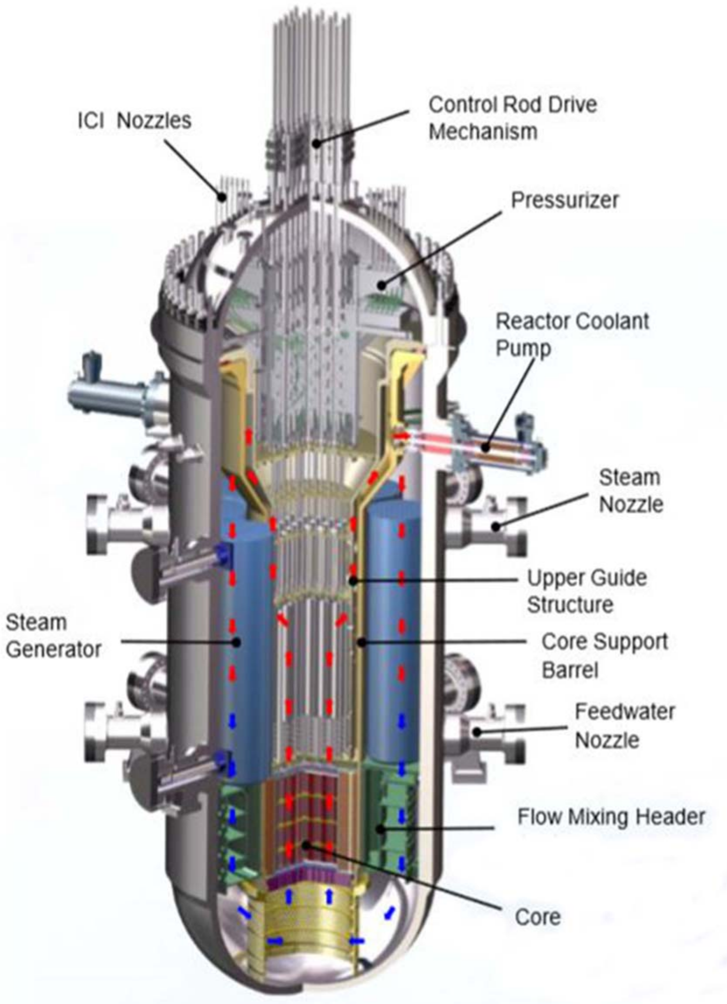


- Main features:
  - Integrated design: primary pumps, pressurizer and heat-exchangers inside the RPV.
  - Passive residual heat removal system (PRHRS for long term cooling).
  - Large internal cooling source (Sump-integrated IRWST).

Source: Kang, H., Han, H., & Kim, Y. (2014). Thermal Sizing of Printed Circuit Steam Generator for Integral Reactor. Jeju: KAERI.

Main SMART Plant Characteristics

- Core characteristics

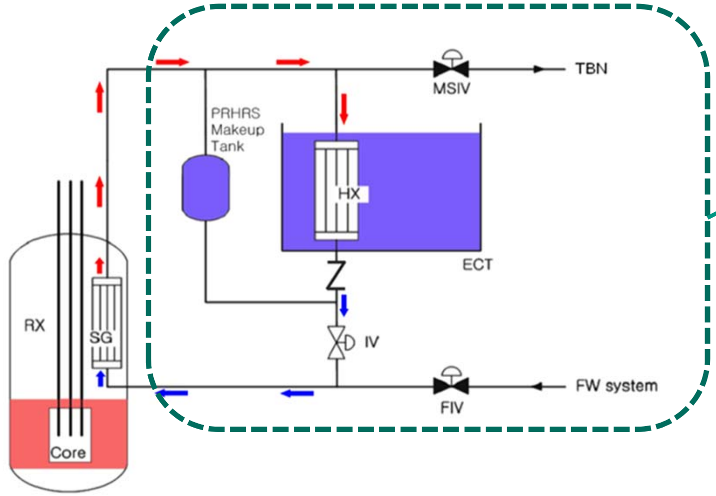


Reactor Type	SMART
Thermal core power	330 MW_{th}
Active core height	2.0 m
Target cycle length	36 months
Fuel Material	< 5 w/o UO_2
FA type	17x17 square
Number of FAs	57
Power density	63 kW/liter
Cooling mode	Forced Circulation
Operating pressure	15 MPa
Core inlet temperature	296 °C
Core outlet temperature	323 °C
Core coolant mass flow rate	2090 kg/s
Steam Generator	Helically Coiled Type (8)
Reactor Coolant Pump	Canned Motor Pump (4)

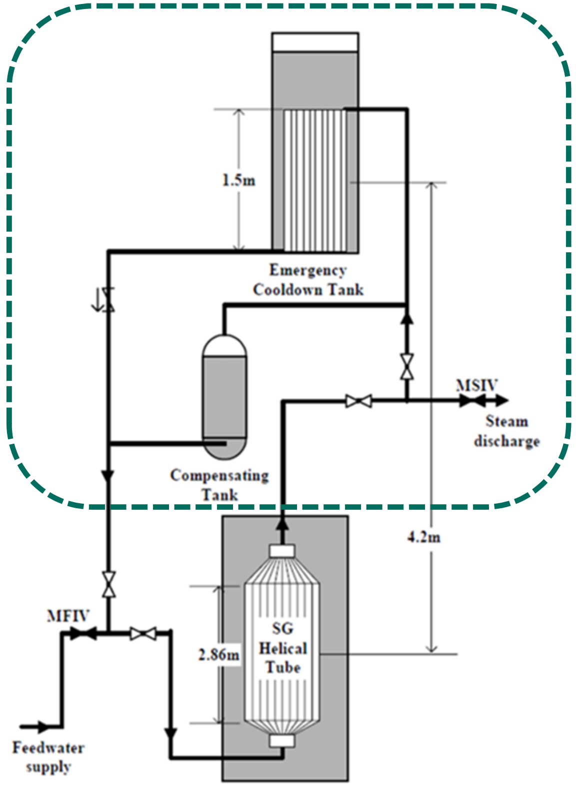
Source: Keun Bae Park, "SMART: An Early Deployable Integral Reactor for Multi-Purpose Applications", INPRO Dialogue Forum on Nuclear Energy Innovations: CUC for Small & Medium-sized Nuclear Power Reactors, 10-14 October 2011, Vienna, Austria

SMART Passive Safety Systems

- Passive Residual Heat Removal System (PRHRS):
  - Emergency cooldown tank
  - Compensating tank
  - Connected to feedwater and steam lines



SMART: Connection of RPV with FW and Steam Lines



SMART: Scheme of PRHRS

Source: Chung, Y. J., Lee, G. H., Kim, H. C., Kim, K. K., & Zee, S. Q. (2004). Parameters which effect the mass flow in the PRHRS under a natural convection condition. KAERI.

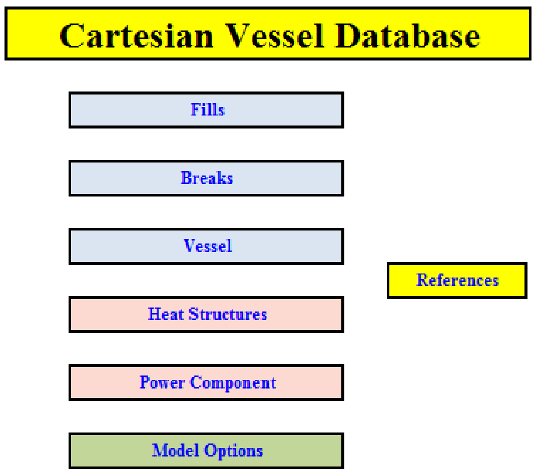
Source: Park, K. B. (2011). SMART An Early Deployable Reactor for Multi-purpose Applications. KAERI.

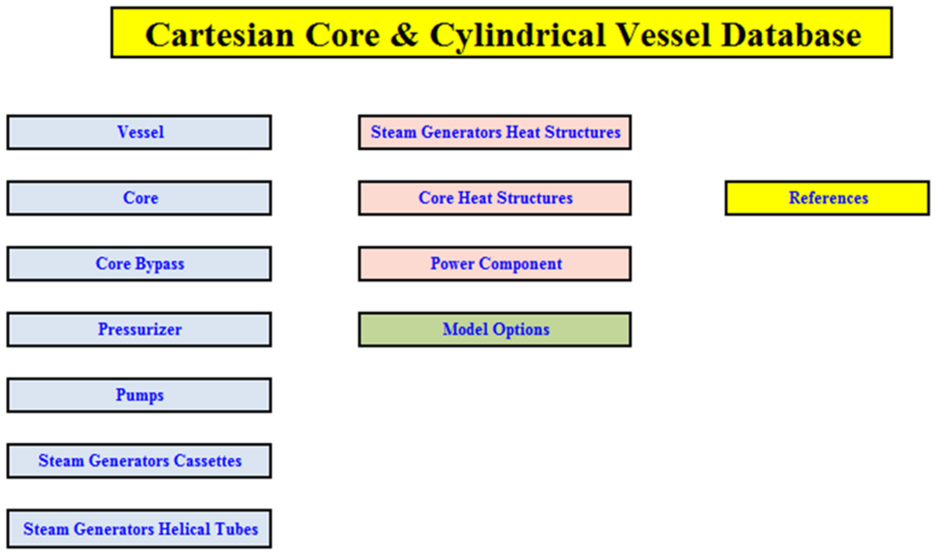
Source: Bae, S., Cho, S., Kang, K., & Park, H. (2016). Application of direct passive residual heat removal system to the SMART reactor. *Annals of Nuclear Energy* .

Numerical Tools and Solution Approach

- Numerical tools used:
  - TRACE system thermal hydraulic code
  - SNAP as pre- and post processor

- Generation of a Data Base with the SMART data needed to develop the TRACE model



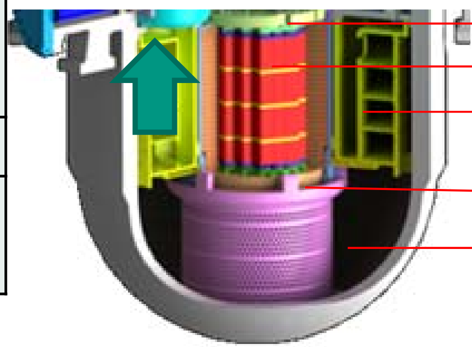


TRACE-Integral SMART Plant Model (1/4)

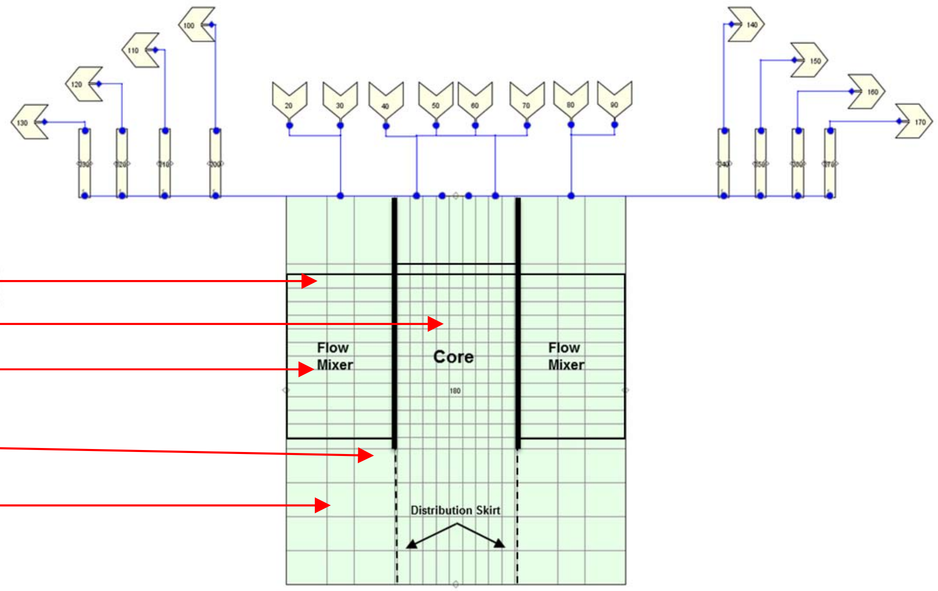
- Model of the RPV and Internals

Axial Levels	Remark
1	Flow mixing/Temperature unifying zone
2	Upper Core Alignment Plate
3	Core
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	Bottom Core Support Plate
16	Lower Plenum
17	
18	
19	

TRACE: Axial Nodalisation



SMART RPV Lower Part



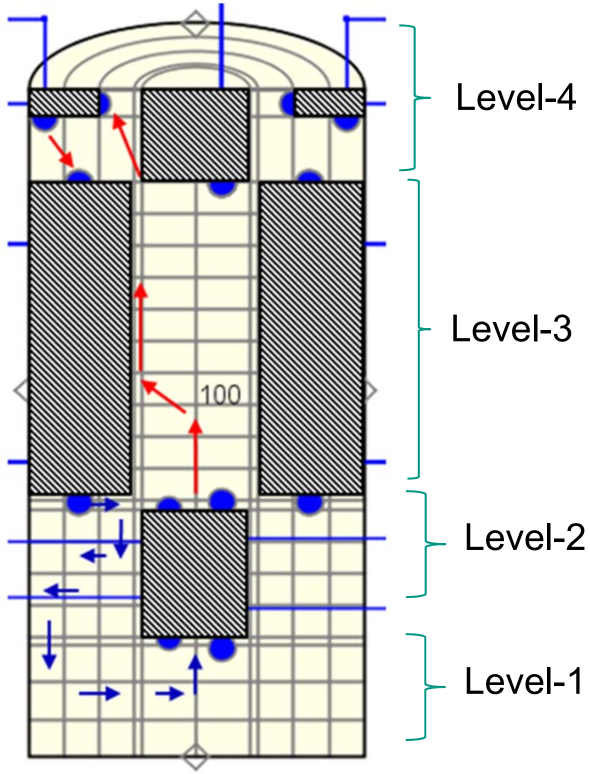
TRACE: 3D Cartesian VESSEL

TRACE-Integral SMART Plant Model (2/4)

- Cylindrical 3D VESSEL Model of RPV

Axial Levels	Unit	Value	Remark	Data Status
21		0,5	Pump	Visual Approximation
20		1,25	Trapezoid	Visual Approximation
19		0,6		
18		0,6		
17		0,6		
16		0,6		
15		0,6	Coolant Temperature Homogenization Zone	SG Height
14		0,6		
13		0,6		
12		0,6		
11	m	0,6		
10		0,6		
9		0,16	Fuel Alignment Plate	Assumed same as Bottom Core Support Plate
8		0,6		
7		0,6	Core	Adopted from Reference (5)
6		0,6		
5		0,6		
4		0,16	Bottom Core Support Plate	Adopted from Reference (14)
3		0,7		
2		0,7	Lower Plenum	Visual Approximation
1		0,7		
Radial levels	**Unit**	**Value**	**Remark**	**Data Status**
1		1,02	Core	Adopted from Reference (26)
2		0,15	Annular Channel	Visual Approximation
3	m	0,6		
4		0,446	Downcomer	Calculated from total vessel diameter
5		0,6		
Azimutal Levels	**Unit**	**Value**	**Remark**	**Data Status**
1		45		
2		45		
3		45		
4	o	45	Steam Generators	Design decision
5		45		
6		45		
7		45		
8		45		

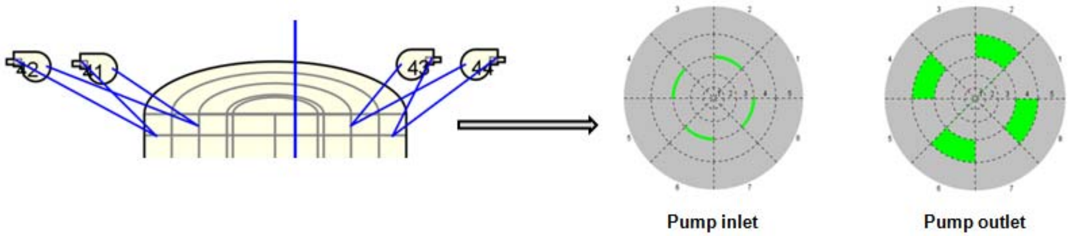
TRACE: Axial Nodalisation



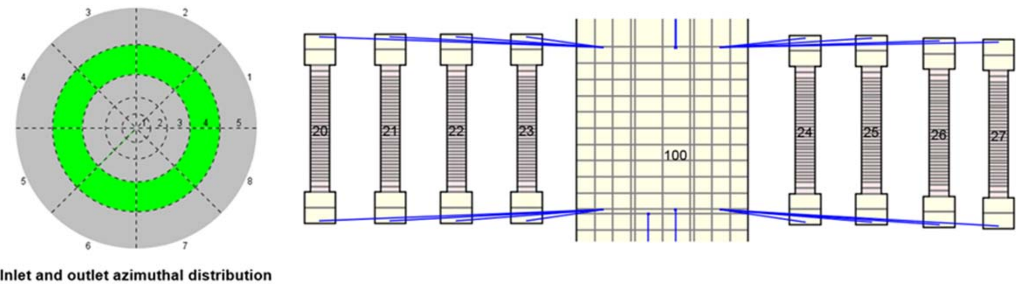
- **Cylindrical Vessel Coolant Path**
  - 4 axial levels to improve flow mixer model
  - better model of core with Cartesian mesh
  - easier representation of horizontal flow though skirt (level 1 to 3 in ring 2)

TRACE-Integral SMART Plant Model (3/4)

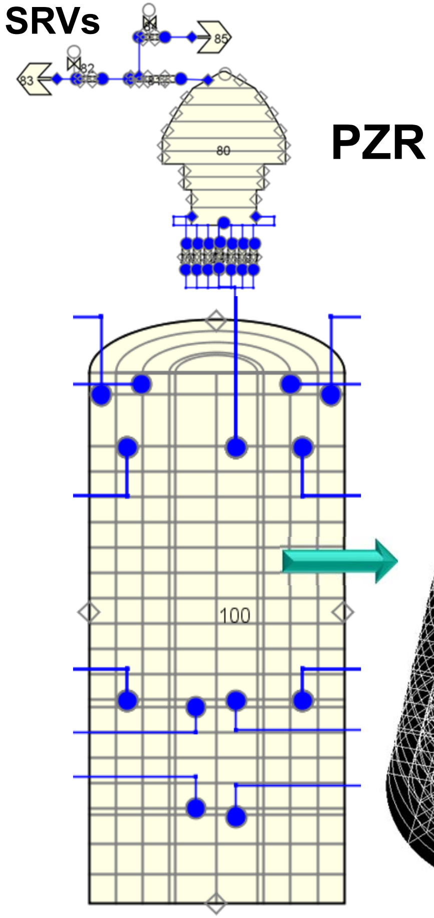
- Cylindrical 3D VESSEL Model of RPV



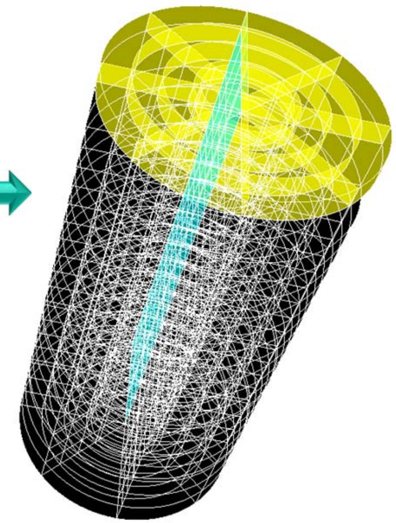
3D VESSEL Model: Location of pumps



3D VESSEL Model: Location of the In-Vessel Heat Exchangers

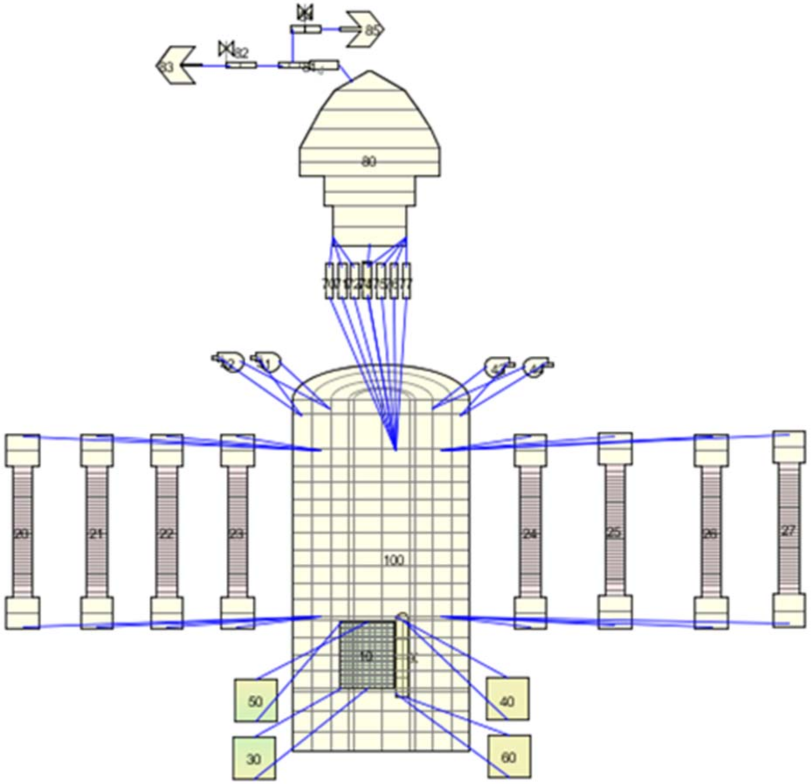


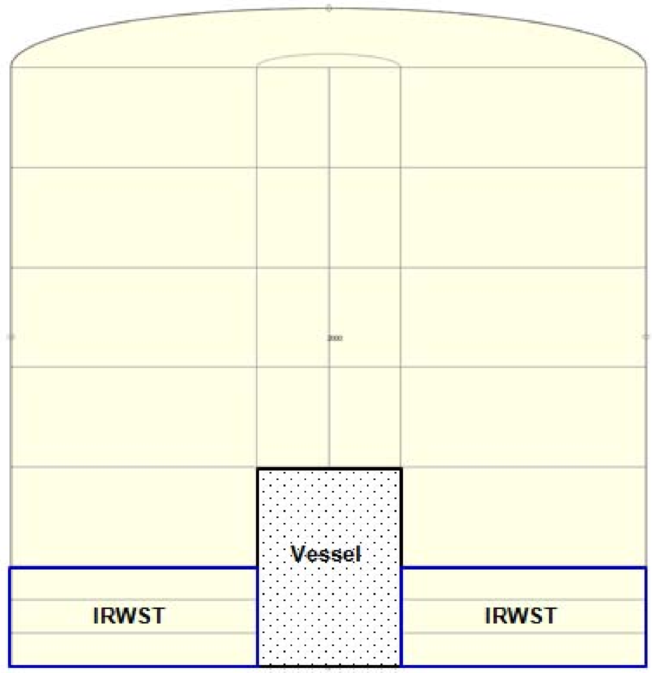
3D VESSEL Cylindrical Model (21x5x8 cells) Blue dots: Connections with the Cartesian core



SNAP Visualization: RPV

TRACE-Integral SMART Plant Model (4/4)





Overall form	Adopted from Reference (24)	-	Cylindrical
Diameter	Adopted from Reference (32)	m	36
Height	Adopted from Reference (32)	m	68,4
Wall Thickness	Adopted from Reference (32)	m	1,4
Volume	Adopted from Reference (32)	m^3	56390
Design Pressure	Adopted from Reference (24)	MPa	0,42

TRACE Integral SMART Model: Simulation Results

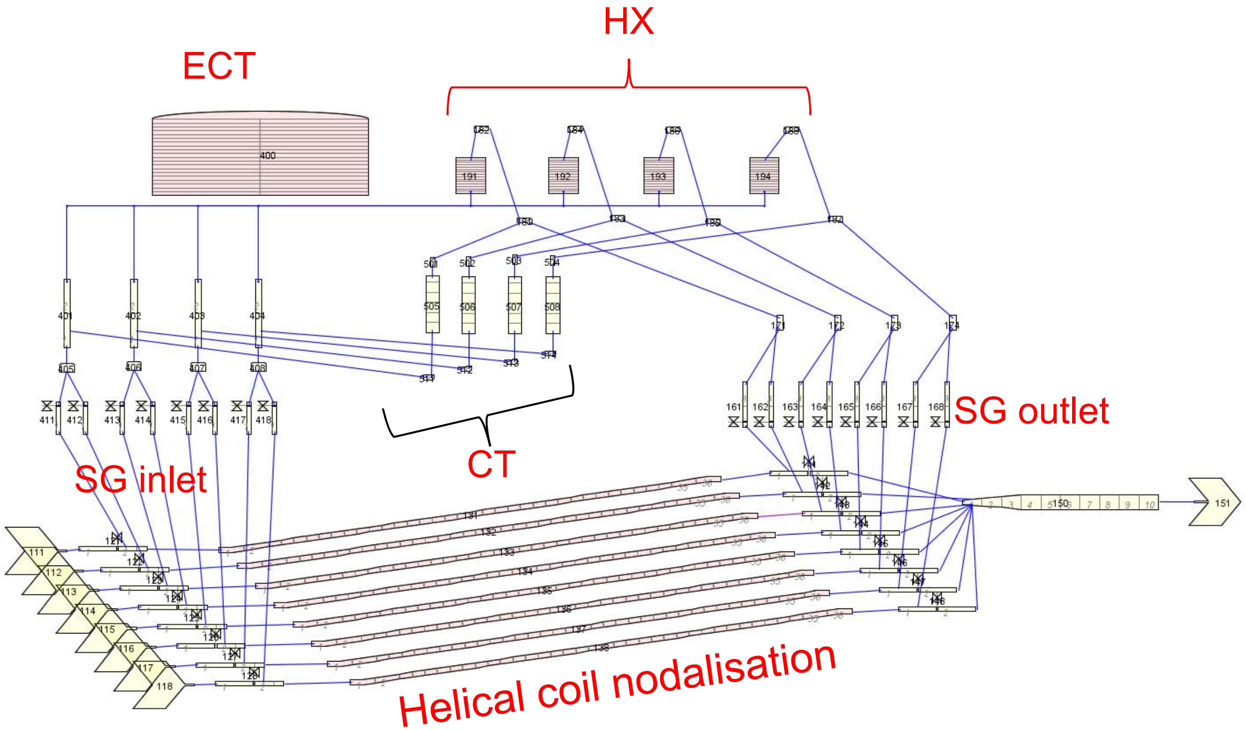
- TRACE steady state simulation
- Steady state reached after 287 seconds

Parameters	TRACE	Reference Data
Inlet Core Temp. (K)	570.26	568.85
Outlet Core Temp. (K)	597,30	596,15
Outlet SG Temp. (K)	567,85	571 (theoretical)
Steam Mass Flow (kg/s)	160,801	160,8
Steam Pressure (Pa)	5,198E06	5,2E06
Reactor Coolant Flow (kg/s)	2090	2090
Bypass Mass Flow (kg/s)	46,56	45,98
Core Mass Flow (kg/s)	2043,44	2044,02
SG Mass Flow (kg/s)	261,25	261
Pump Impeller Speed (rad/s)	178,22	179
Core Pressure Drop (KPa)	35	(values between 5 & 45)
SG Cassette Pressure Drop (KPa)	95	55
SG Coil Pressure Drop (KPa)	180	170

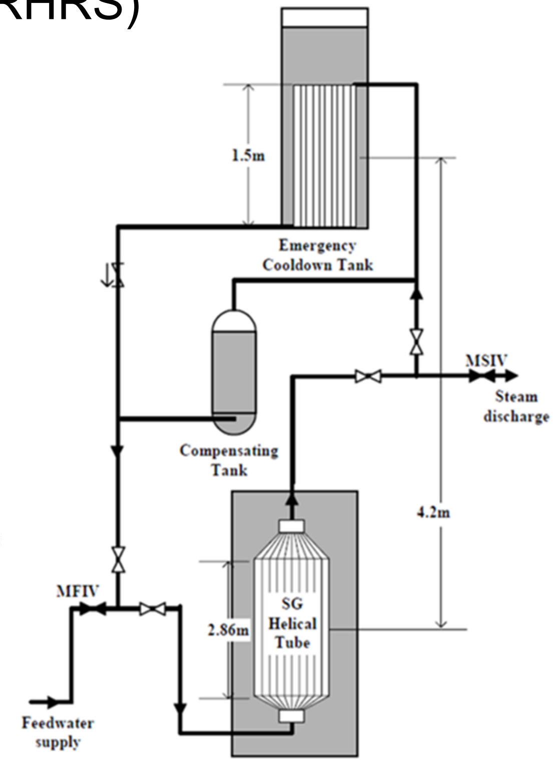
- Observation :
  - TRACE predictions close to reference data find in the open literature
  - Pressure drop over SG-cassette show largest deviation
  - Further improvement necessary ➔ close contact with SMART developers needed! (detailed design information)

TRACE-Model of PRHRS

- Depiction of Passive Residual Heat Removal System (PRHRS)



TRACE Model of the Secondary Side:
- **Connections with the Passive Residual Heat Removal System.**

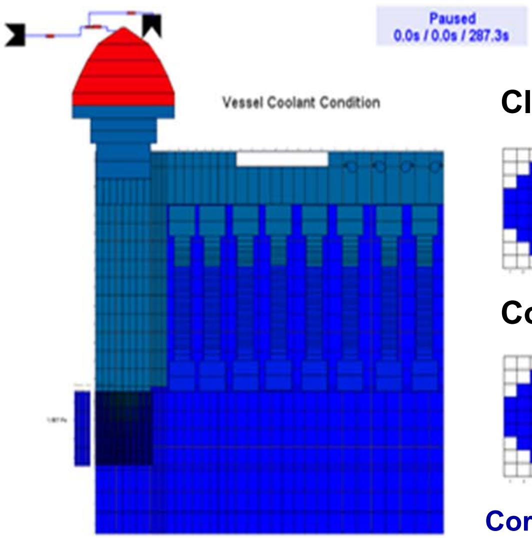


SMART: Scheme of PRHRS

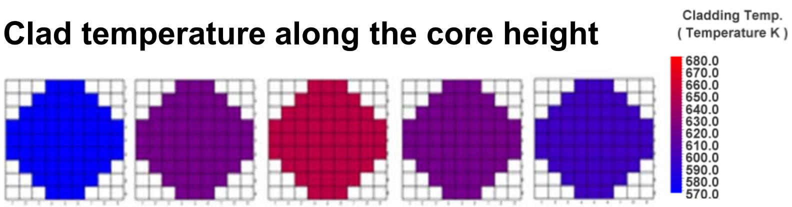
ECT=Emergency Cooldown Tank
CT =Compensating Tank
SG = Steam Generator
HX =Heat Exchanger

Source: Chung, Y. J., Lee, G. H., Kim, H. C., Kim, K. K., & Zee, S. Q. (2004). Parameters which effect the mass flow in the PRHRS under a natural convection condition. KAERI.

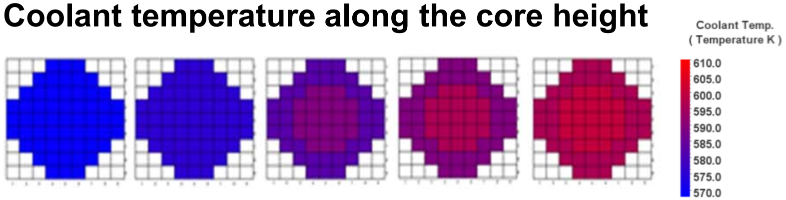
SMART SS: SNAP Visualization of Key Parameters



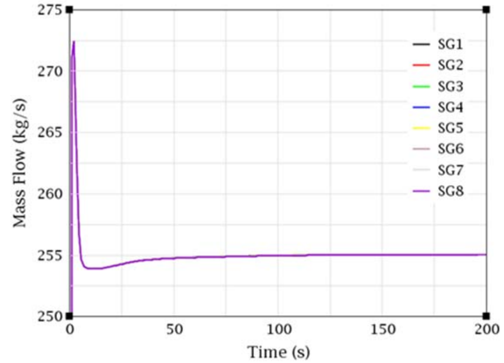
Clad temperature along the core height



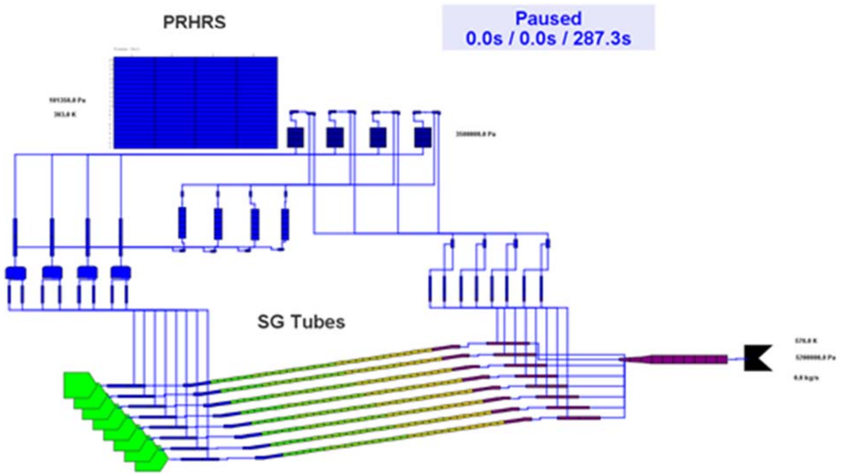
Coolant temperature along the core height



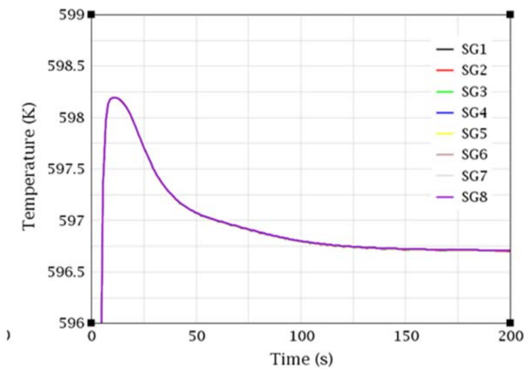
Core bottom **Core Top**



TRACE: Convergence behaviour of mas flow rate through all SGs (8)



SMART: SNAP Visualization of Secondary Side



TRACE: Convergence behaviour of the Coolant temperature at the SG-inlet

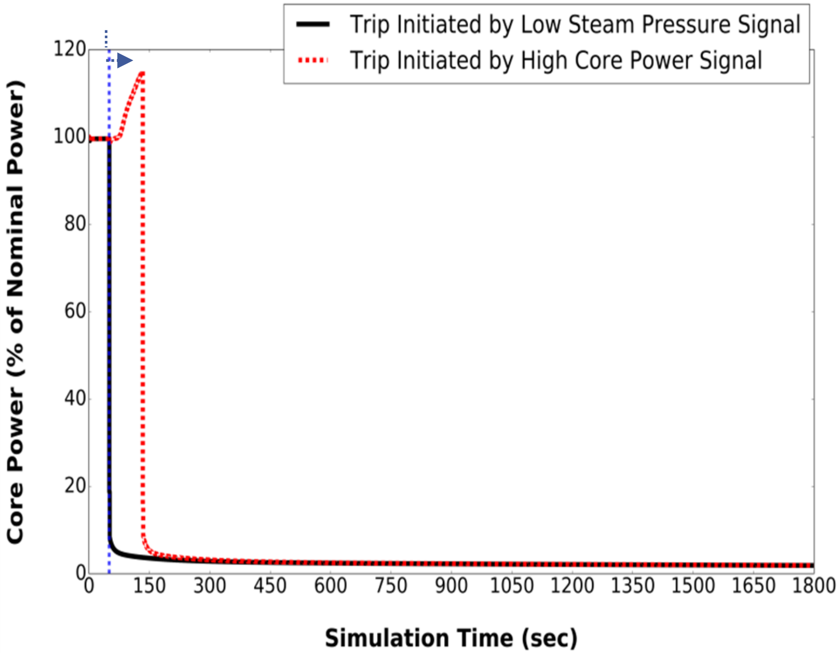
Summary

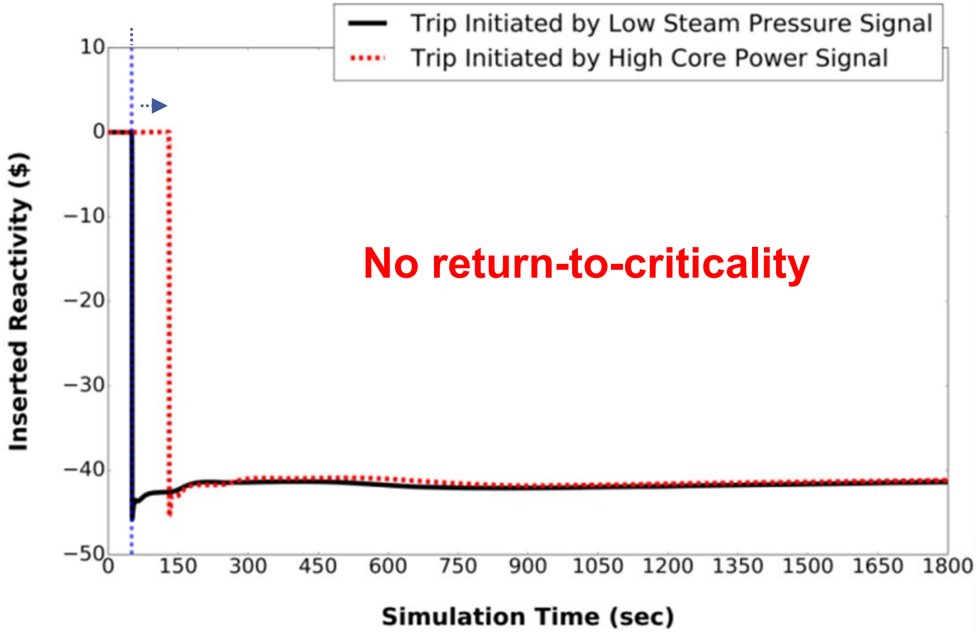
- Integral model of the SMART plant developed using public available data
  - Comparison of TRACE-prediction with reference data is promising
  - For further improvements close contact with SMART-developers needed
- Integral TRACE model includes also safety systems and hence it is ready to be used for transient analysis of SMART
  - Using point kinetics models e.g. TRACE + PK or
  - Coupled with a 3D core model e.g. PARCS/TRACE model

Outlook

- KIT developed a new core design (KSMR core) from scratch which can be integrated in the SMART-plant (**boron free core**).
- Currently selected KSMR-transients are analysed with coupled codes (PARCS/SCF and TRACE/PARCS) e.g. REA and Steam Line Break (SLB).

SLB occurrence



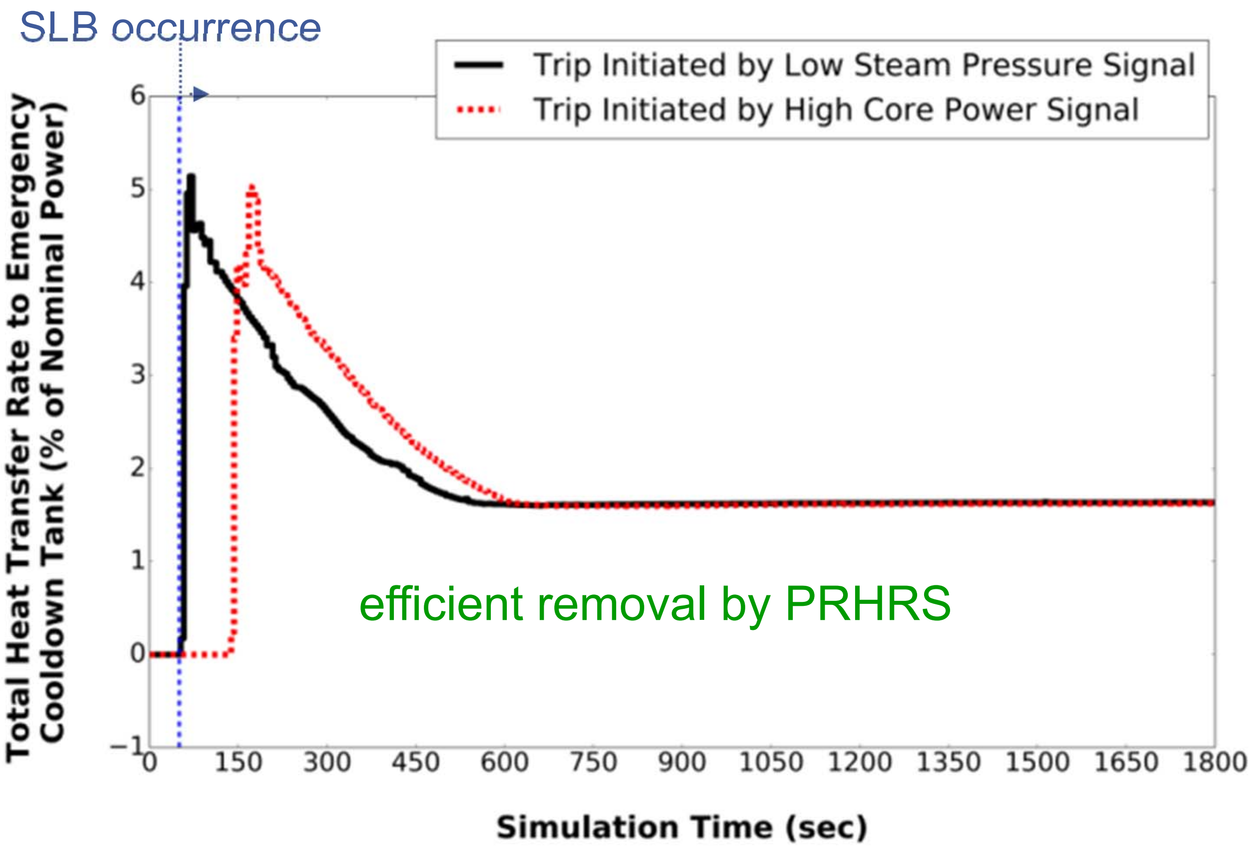


KSMR behaviour under SLB predicted by TRACE/PARCS

Source: Y. Alzaben, V. Sanchez, R. Stieglitz; "Simulation of KSMR Core Zero Power Conditions Using The Monte Carlo Code Serpent", 48th Annual Meeting on Nuclear Technology (AMNT 2017), Berlin, Germany, May 16-17, 2017

Outlook

- Longterm decay heat removal feasible ?



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announcement of 25th Frédéric Joliot & Otto Hahn Summer School on nuclear reactors "Physics, Fuels and Systems" 2019

"Innovative Reactors: Matching the Design to Future Deployment and Energy Needs"

21st-30th August 2019 in Karlsruhe

Topics to be covered

- Close to maturity innovative reactor concepts for various purposes/missions
- Near-term deployment power-to-grid LWR technology
- Multi-mission liquid fuel reactors
- Space propulsion/deep space exploration
- Minimal operation and intervention reactors
- Power provision in remote areas , versatile reactors
- Group Reflection, Seminar