Application of ATHLET/DYN3D/CTF to BWR TT without SCRAM

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- Presentation of the codes
  - DYN3D, ATHLET (and CTF)
- System and Models description
- Transient description
- Simulation results and comparison

Description of the NURESAFE Sub-Project 1.3

- The objective is to develop and execute simulation schemes using the NURESAFE codes to analyse a BWR ATWS transient coupled with Uncertainty Quantification (UQ)
- The term 'ATWS' covers a broad range of transients. The selection of the transient has a strong influence on the event sequence and thus on the systems involved, the range of variations of the feedback parameters, etc…
- In order to develop the input model for each code, an accurate description of the BWR system and core characteristics is needed. For this reason, the Peach Bottom 2 reactor from the OECD/NEA Boiling Water Reactor (BWR) Turbine Trip (TT) Benchmark was selected
- The selected transient is the Turbine Trip without SCRAM which is also part of the OECD/NEA Benchmark (Extreme Scenario #2)

Presentation of the DYN3D code

- 3D neutron kinetics code developed at the HZDR
  - Nodal expansion methods, two-group diffusion theory
  - Multi-group transport (SP3) approach with pin-wise resolution
  - Hexagonal FE geometry (VVER, GEN IV Systems)
  - Square FE (PWR, BWR)
  - Connection to various macroscopic XS libraries format
- Two-phase coolant flow in parallel channels thermo-mechanical fuel rod model
  - Estimation of safety relevant parameters (critical heat flux, max. fuel and cladding temperatures, oxide layer thickness)

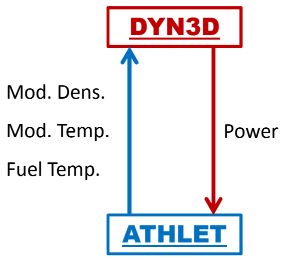
Presentation of the ATHLET code

- TH system code developed at the GRS
- 1D hydraulic model
- Two-phase flow is described by 4 to 6 equation models
  - Liquid and Vapor mass conservation
  - Mixture or Liquid + Vapor energy conservation
  - Mixture or Liquid + Vapor momentum conservation
- Parallel channels representation of the core with/without cross flow connections

Coupling of codes on the platform

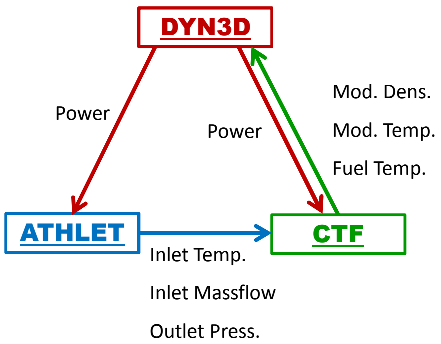
Option 1

- Typical NK/TH internal coupling



Option 2: Advanced case

- 3-way coupling

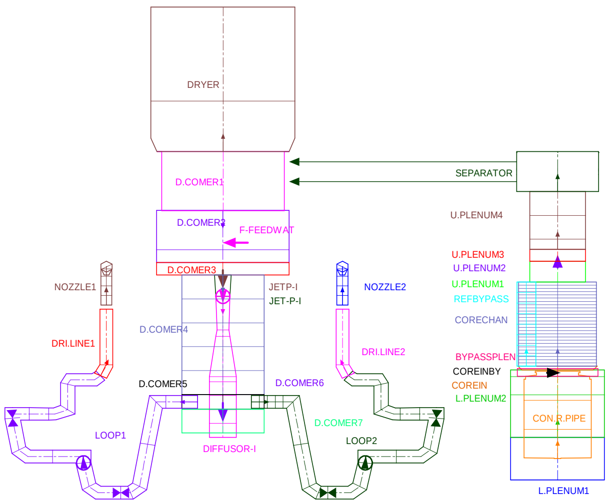


Description of simulated BWR system

- Peach Bottom 2 reactor
  - GE designed BWR/4
  - 3293 MWth
  - 764 fuel bundles
  - 7x7 and 8x8 fuel rod arrays

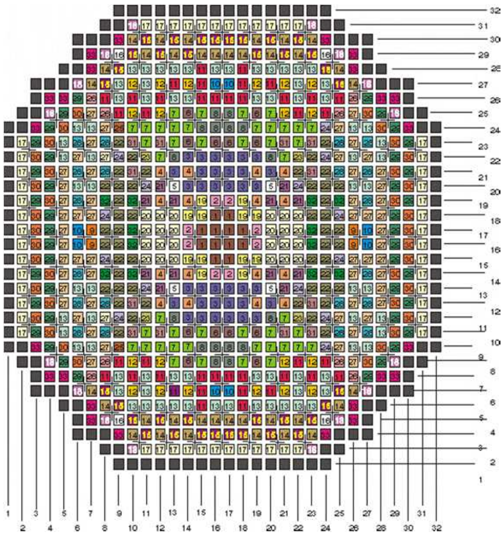
ATHLET Model Description

- ATHLET plant model (without main steam line)



ATHLET Model Description

- ATHLET 33 core channel model
  - Mapping scheme used for the OECD Benchmark



CTF Model description

- All 764 fuel bundles are modelled separately (1:1 mapping scheme)
- No bypass is modelled in CTF
- The fuel bundles are of three different TH types
- The core is divided into three radial zones with different inlet orifices
- The CTF core model is coupled to the ATHLET 33- channel model at core inlet (massflow and enthalpy) and outlet (pressure)

Assembly Type	1,2 & 3	4 & 5	6
No. of assemblies in core	576	68	4
Geometry	7x7	8x8	8x8
Fuel rod per assembly	49	63	62
Water rods per assembly	0	1	2

DYN3D Model description

- 19 assembly types are defined
  - Assembly type #19 is the reflector
- 24 axial nodes in the active core are used
  - A total of 18*24*2 + 3 = 867 XS sets are defined (including the controlled status)
- The burnup and the historical parameters are implicitly included in the macroscopic cross-section
- 6 moderator density branching points
  - 141.595, 226.1546, 299.6453, 435.0457, 599.1722 and 779.4058 kg/m³
- 5 fuel temperature branching points
  - 400, 800, 1200, 1600 and 1800 K

DYN3D Model description

- Core loading pattern

								19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19								
							19	19	11	5	6	6	7	6	6	6	6	7	6	6	5	11	19	19							
					19	19	19	6	6	1	6	1	6	1	1	1	1	6	1	5	1	6	6	19	19	19					
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				19	19	6	7	1	16	10	16	16	18	18	15	16	17	18	16	16	10	16	1	7	6	19	19				
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		19	8	6	10	1	17	10	17	12	15	14	17	13	17	17	13	16	14	15	12	15	10	15	1	10	6	8	19		
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							19	19	11	5	6	5	6	6	6	6	6	6	6	5	5	11	19	19							
								19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19								

ATWS Scenario

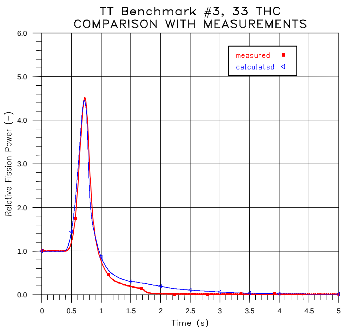
- Turbine Trip initial conditions
  - 61.6% of rated power
  - 80.9% core flow
  - Control rods partially inserted

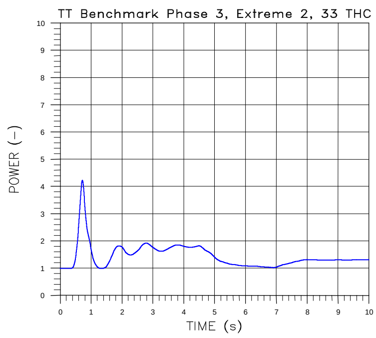
- Benchmark extreme scenario #2 = Base scenario without scram (ATWS)

- Scenario
  - t = 0 s – Turbine stop valve starts to close
  - t = 0.060 s – Bypass valve starts to open
  - t = 0.096 s – Turbine stop valve is fully closed
  - ~~t = 0.75 s – Reactor trip~~
  - t = 0.846 s – Bypass valve is completely open

ATWS Scenario

- Expected results (ATHLET-QUABOX/CUBBOX simulation from official Benchmark results)





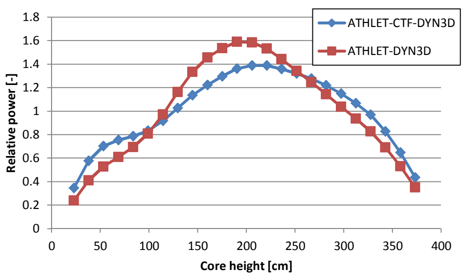
Relative power history: Left = reference scenario – Right = Extreme scenario #2

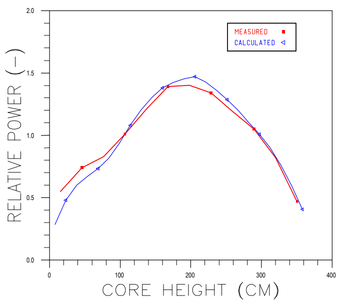
Steady state results

- Steady-state iterations
  - Option 1: ATHLET ↔ DYN3D
  - Option 2: CTF ↔ DYN3D
- 30s seconds of 0-transient during which DYN3D is still in steady-state mode (called every second)
- 2s where all codes are in transient mode but only the regulation systems are activated
- t=32s → Start of the Turbine Trip Transient

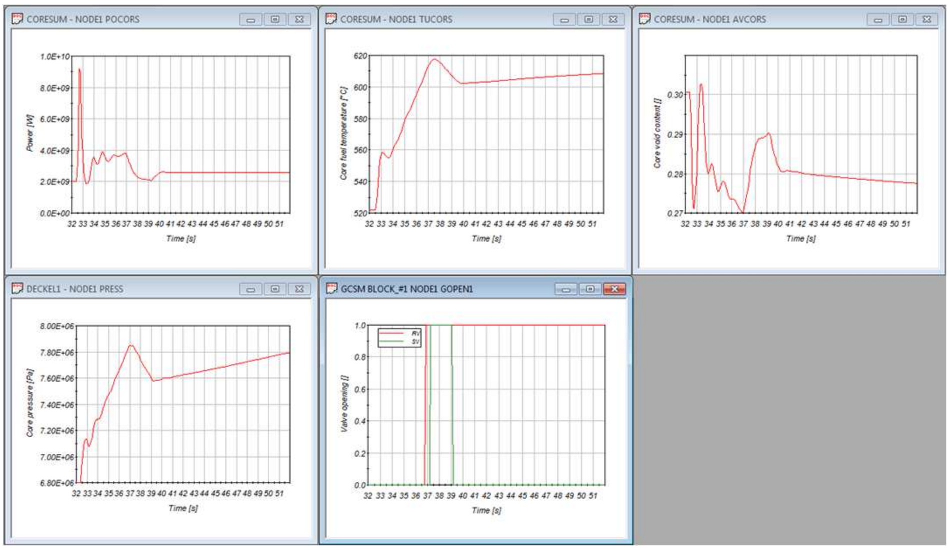
Steady state results (after 0-transient)

- Keff
  - ATHLET-DYN3D (Salomé) = 1.00500
  - ATHLET/QC = 1.00533
  - ATHLET/CTF/DYN3D (Salomé) = 0.99504





Global parameters: ATHLET-DYN3D



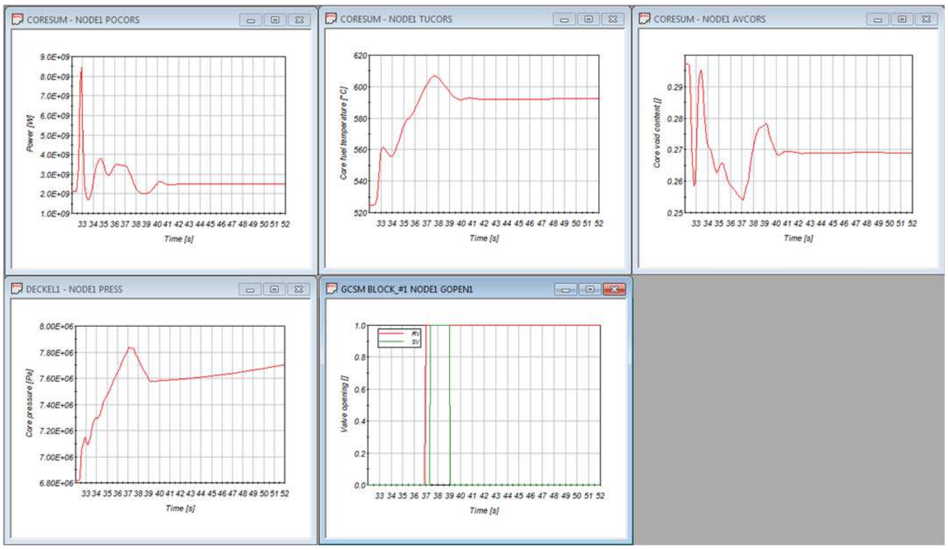
Results description

- The nuclear power is driven by the increase in pressure, which causes a void collapse in the core
- The positive power response is almost immediate, but the transient is slowed down by the feedback from the increased direct and conducted heat flux to the coolant, which will, in turn, produce void and give a negative reactivity feedback
- The fuel temperature rise is moderate and the Doppler effect plays a subordinate role, compared to the void effect
- In the normal case, the scram is triggered at a defined power level and stops the transient

Results description

- In the ATWS case, no SCRAM takes place
- The reactor power shows an oscillatory behaviour driven by the interactions between power and feedback mechanisms
- This behaviour is interrupted by the opening of the Release and Safety Valves which stabilized the pressure and the power

Global parameters: ATHLET-CTF-DYN3D



Key parameters: Comparison

- Maximum power
  - ATHLET-DYN3D = 9.2 GW (0.7 s after TT)
  - ATHLET-CTF-DYN3D = 8.4 GW (0.8 s after TT)

- Valves Opening/Closing

	RV -1		RV - 2		RV - 3		SRV	
	open [sec]	close [sec]	open [sec]	close [sec]	open [sec]	close [sec]	open [sec]	close [sec]
ATHLET-DYN3D	4.8	-	5.2	7.2	-	-	-	-
ATHLET-CTF-DYN3D	5.0	-	5.4	7.1	-	-	-	-

Uncertainty Quantification of BWR ATWS

- Use of the URANIE platform with the ATHLET-DYN3D model
- Selection of uncertain parameters
  - Initial / Boundary conditions
    - Pressure
    - Recirculation massflow
    - Feedwater massflow
    - Etc…
  - TH modelling
    - Spacer pressure loss coefficient
    - Fuel/Cladding gas gap conductance
    - Fuel conductivity
    - Etc…
  - Neutronic parameters
    - Doppler coefficient
    - Void coefficient

Conclusions

- BWR Turbine Trip Without SCRAM was successfully simulated with NURESIM tools

- Effect of Thermal-hydraulic model in core
  - ATHLET-DYN3D legacy model with 33 TH-channels in the core
  - Advanced three-way coupling scheme ATHLET-CTF-DYN3D with 1:1 mapping scheme

- As expected, coarser model deliver more conservative results regarding the first power peak

- An uncertainty quantification was performed with the URANIE tool on the basis of the ATHLET-DYN3D model (= Main objective of NURESAFE SP13)