Overview of the RELAP5-3D code activities in ENEA

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  - OECD/NEA KALININ 3 benchmark
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Framework - ENEA & the SIMING Lab

- **ENEA** is the Italian National Agency for New Technologies, Energy & Sustainable Economic Development
- A branch of **ENEA** actively involved in *researches* for fission nuclear power technology
  - Research Reactors (e.g., TRIGA & Tapiro)
  - Experimental Engineering (e.g., AP600 components testing)
  - Nuclear Material Characterization
  - Models & Simulation
  - Integrated Services (e.g., waste management)
  - Metrology & Radioprotection
  - Advanced Nuclear Systems (e.g., Gen IV, LFR)

- The **ENEA-SIMING Lab** performing R&D activities on NPP simulations & engineering simulators at the Casaccia Research Center (Rome)

- Acting as *Technical Support Organization* (TSO) for the Italian Nuclear & Industrial Safety Authority (ISPRA)
Recent activities using RELAP5-3D code

- RELAP5-3D code used for studying NPP transients and accidents
- Participating to coupled code benchmarks organized by OECD/NEA
  - “KALININ-3”: VVER-1000 MCP-1 switch off @ HFP
  - “OSKARSHAMN-2”: BWR Global Core Instability Event

Objectives:
- to explore the capabilities of the coupled codes in simulating NPP behavior during AOO/DBA
- to quantify codes and models uncertainties
Recent activities using RELAP5-3D code

- **KALININ-3 benchmark**
  - Model developed in the past years
  - Presented in the last IRUG meeting
  - Final results being submitted to the benchmark organizers by the end of the year
  - Primary & secondary circuits modeled
    - 3D TH components for RPV
    - 3D NK core model
    - Detailed TH nodalization for selected FA
  - Demonstrated capabilities of RELAP5-3D in modeling core asymmetric coolant temperature perturbations with high resolution degree
Recent activities using RELAP5-3D code

- **OSKARSHAMN-2 benchmark**
  - Launched by OECD/NEA last year → release 1.0 of specifications → definition of several parameters still in progress
  - Previous instability benchmarks (Forsmarsk and Ringhals) characterized by decay ratio < 1.0 & based on noise measurement of a stable reactor
  - **O-2 1999 event** is an instability event with a DR > 1 (diverging oscillation)
  - Challenging simulation for a coupled code
    - Detailed RPV/core nodalization needed
    - Core parameters changing on a great magnitude
      - Core power going from 60% up to 130%
    - Tightly coupled NK-TH transient
The Oskarshamn NPP
## Reactor Coolant System modelling

### Design operating conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated thermal power</td>
<td>MWt</td>
<td>1700</td>
</tr>
<tr>
<td>Dome pressure</td>
<td>MPa</td>
<td>7.0</td>
</tr>
<tr>
<td>Steam flow rate</td>
<td>kg/s</td>
<td>900.0</td>
</tr>
</tbody>
</table>

### Reactor pressure vessel geometry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal height</td>
<td>m</td>
<td>20.0</td>
</tr>
<tr>
<td>Internal diameter</td>
<td>m</td>
<td>5.2</td>
</tr>
<tr>
<td>Weight</td>
<td>t</td>
<td>530.0</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>mm</td>
<td>134.0</td>
</tr>
</tbody>
</table>

### Core geometry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent core diameter</td>
<td>mm</td>
<td>3672</td>
</tr>
<tr>
<td>Equivalent core height</td>
<td>mm</td>
<td>3712</td>
</tr>
<tr>
<td>Number of fuel bundles</td>
<td>-</td>
<td>444</td>
</tr>
</tbody>
</table>

### Control rods

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Absorbing material</th>
<th>Number of CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorbing material</td>
<td>B₄C</td>
<td>109</td>
</tr>
<tr>
<td>Number of CR</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
The 1999/02/25 event

Rated Power: 1700 MW

Event Description

1. Turbine trip and bypass valves opening
2. First 108% power level exceeding
3. Stop Reducing pump velocity
4. Second 108% power level exceeding
5. Stop Reducing pump velocity
6. Third 108% power level exceeding
7. Stop Reducing pump velocity
8. Operator Partially scrammed the reactor and reduced to the minimum the pump velocity.
9. Reactor enter in the unstable region of the power/flow map
10. The reactor scrammed because the power exceeded 132%
RELAP5-3D© used for the Oskarshamn-2 benchmark simulation of:

- TH phenomena (1D & 3D components)
- 3D NK (internal routine based on the NESTLE code; 2 group diffusion equation)
RCS TH nodalization

- Number of Hydraulic volumes: **489** (core channels and bypass not included)
- **4** recirculation loops with external pumps (collapsed in one)
- **4** steam lines (collapsed in one)
- Passive Heat structures still not simulated
4 Different FA type of different fuel vendors present in the core
Core modelling

444 Channels core nodalization
Core modelling

- **110** interconnected branches at the inlet/outlet of the core.
Core Axial meshing:
- Uniform meshing for the active part 25 Hydraulic mesh + 25 Thermal mesh + 25 Neutronic mesh
- 3 Hydraulic mesh + 2 Neutronic mesh for the bottom & top reflector
- 1 Hydraulic meshes for FA inlet zone

Core statistics
- 444 independent TH channels +1 (Bypass)
- 12876 Hydraulic volumes + 29 (Bypass)
- 14472 NK nodes (including Reflector)
Several Benchmark “Uncertainties” identified

- Cross section library specifications (NEMTAB format still not available, CR specifications)
- Channels pressure drop coefficients
- Materials thermal capacity and conductivities
- Configuration of the channel connection to the lower plenum

- Missing data replaced by engineering judgment and in-house developed tools (e.g., CASMO Xsec interpolator)
<table>
<thead>
<tr>
<th>NAME</th>
<th>u.d.m</th>
<th>NPP</th>
<th>NPP Code</th>
<th>RELAP5-3D</th>
<th>Rel. error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Power</td>
<td>MW</td>
<td>1798.6</td>
<td>1802</td>
<td>1798.6</td>
<td>IMPOSED</td>
</tr>
<tr>
<td>Steam Dome Pressure</td>
<td>MPa</td>
<td>6.93</td>
<td>7.00</td>
<td>6.94</td>
<td>0.12%</td>
</tr>
<tr>
<td>Core Inlet Pressure</td>
<td>MPa</td>
<td>N/A</td>
<td>7.166</td>
<td>7.095</td>
<td>-0.99%</td>
</tr>
<tr>
<td>Core Outlet Pressure</td>
<td>MPa</td>
<td>N/A</td>
<td>7.067</td>
<td>6.996</td>
<td>-1.00%</td>
</tr>
<tr>
<td>Core ΔP</td>
<td>kPa</td>
<td>N/A</td>
<td>98.8</td>
<td>98.5</td>
<td>-0.34%</td>
</tr>
<tr>
<td>Channel ΔP</td>
<td>kPa</td>
<td>N/A</td>
<td>46.0</td>
<td>50.8</td>
<td>10.36%</td>
</tr>
<tr>
<td>Orifice &amp; Lwr plate ΔP</td>
<td>kPa</td>
<td>N/A</td>
<td>52.8</td>
<td>47.7</td>
<td>-9.66%</td>
</tr>
<tr>
<td>Core Average Void</td>
<td>//</td>
<td>N/A</td>
<td>0.42</td>
<td>0.44</td>
<td>4.19%</td>
</tr>
<tr>
<td>Core Average Fuel Temp</td>
<td>K</td>
<td>N/A</td>
<td>816.7</td>
<td>854.7</td>
<td>4.65%</td>
</tr>
<tr>
<td>Feed water Temperature</td>
<td>K</td>
<td>457.6</td>
<td>N/A</td>
<td>457.7</td>
<td>IMPOSED</td>
</tr>
<tr>
<td>Core Inlet Temperature</td>
<td>K</td>
<td>547.30</td>
<td>548.05</td>
<td>547.1</td>
<td>-0.03%</td>
</tr>
<tr>
<td>Steam Temperature</td>
<td>K</td>
<td>N/A</td>
<td>N/A</td>
<td>557.9</td>
<td>N/A</td>
</tr>
<tr>
<td>Pump Speed</td>
<td>Rad/s</td>
<td>N/A</td>
<td>N/A</td>
<td>99.78</td>
<td>N/A</td>
</tr>
<tr>
<td>Total Core Flow Rate</td>
<td>kg/s</td>
<td>5474.0</td>
<td>5515.9</td>
<td>5474.0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Active Core Flow Rate</td>
<td>kg/s</td>
<td>N/A</td>
<td>4793.5</td>
<td>4759.7</td>
<td>-0.70%</td>
</tr>
<tr>
<td>Steam Flow Rate</td>
<td>kg/s</td>
<td>900.0</td>
<td>976.0</td>
<td>904.5</td>
<td>0.50%</td>
</tr>
<tr>
<td>Downcomer Water Level</td>
<td>m</td>
<td>N/A</td>
<td>N/A</td>
<td>8.4</td>
<td>N/A</td>
</tr>
<tr>
<td>K-eff</td>
<td>//</td>
<td>N/A</td>
<td>1.0026</td>
<td>1.0056</td>
<td>30 pcm</td>
</tr>
</tbody>
</table>
Steady state results

Mass Flow Rate, Pressure and Temperature convergence

- Bypass
- Steam line
- Steam line (Measured)
- Steam Dome
- Core Outlet
- Core Inlet
- Core Inlet (Measured)
- Core Inlet (Measured)

Total Core
- Total Core (Measured)
- T Sat Core Inlet
Steady state analysis results

- Power Radial shape factor and relative error for all 444 FA
Steady state analysis results

Axial core values

Axial power shape factor

Axial averaged fuel temperature

Axial averaged void fraction
Steady state analysis results

- Mass flow rate and relative error for all 444 FA
Steady state analysis results

- Exit void fraction and P/G factor for all 444 FA

![Heatmap of exit void fraction and P/G factor](image-url)
Transient analysis results

Boundary conditions

Feed-water Mass flow rate

Feed-water Temperature

Steam Line Pressure

Pump speed
Transient analysis results

- Recirculation MFR, SD Pressure, SL MFR, Power Flow map

- Recirculation Mass Flow Rate (%)
  - Measured
  - RELAPS-3D

- SD Pressure (Pas)
  - Measured
  - RELAPS-3D

- Steam Line mass flow rate (kg/s)
  - Measured
  - RELAPS-3D

- Total Core power (%)
  - P-G Graph
  - Starting point
  - Final Point
Transient analysis results

- Total core Power

![Graph showing measured and RELAP5-3D total core power over time](image-url)
Transient analysis results

- Average clad Temperature Vs. Hot Spot temperature

![Graph showing average clad temperature vs. hot spot temperature over time](image-url)
Transient analysis results

- Animation
Sensitivity analysis results

- +/- 10 % Heat Capacity of UO₂ and Clad

- +/- 10 % GAP Conductance
Sensitivity analysis results

- +/- 3 K feed water temperature
- +/- 1 s CR insertion time
Main issues during nodalization development/code run

1. Limitation on TH mapping did not allow to connect 1:1 the TH volumes & NK nodes (9999 zone figures available vs. 444x25=11100 requested) → some “homogenization” needed → Q: is it possible to increase the zone figures number in future releases?

2. Possibility to implement the large CASMO Xsec database (9999 compositions available) → conflicting with the input deck length → “Input too long” error message (R5v.3.0beta)

3. Implementation of Xsec cross terms & “online” Xsec interpolation not possible
Conclusion & future steps

- ENEA is using R5-3D code as reference tool for NPP simulation

- Oskarshamn-2 BWR state-of-the-art model for RELAP5-3D© system code has been developed
  - detailed 3D neutronic coupled thermal-hydraulic model
  - developed for instability analyses → Oskarshamn-2 Feb. 1999 event

- Steady state and on transient preliminary qualification achieved
  - Main «uncertainties» of the data set identified and their effect on simulation result assessed

- Future steps for the model qualification: performing blind calculations simulating the 1999 O-2 stability tests