Recent Applications of RELAP5-3D at GRNSPG


2012 RELAP5 International User’s Group Seminar And Meeting
Sun Valley, ID, Oct 23-24, 2012
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

4 MOD LOOPS
1 PU, 1 HEX each

ARROWS indicate nominal moderator flow directions

Gruppo Ricerca Nucleare S. Piero a Grado

# The Atucha-2 NPP

<table>
<thead>
<tr>
<th>No</th>
<th>Transient</th>
<th>Section FSAR</th>
<th>Adopted Evaluation Model</th>
<th>Class of Accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Spectrum of LOCA (part 2 of 2)</td>
<td>15.6.5.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>51</td>
<td>Primary Coolant System LOCA</td>
<td>15.6.5.1.1.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>52</td>
<td>Small Break LOCA</td>
<td>15.6.5.1.1.1</td>
<td>CSA</td>
<td>DBA</td>
</tr>
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<td>53</td>
<td>30 cm² LOCA cold</td>
<td>15.6.5.1.1.1</td>
<td>CSA</td>
<td>DBA</td>
</tr>
<tr>
<td>54</td>
<td>100 cm² LOCA cold</td>
<td>15.6.5.1.1.2</td>
<td>CSA</td>
<td>DBA</td>
</tr>
<tr>
<td>55</td>
<td>Break of the Refueling Nipple</td>
<td>15.6.5.1.1.3</td>
<td>CSA</td>
<td>DBA</td>
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<tr>
<td>56</td>
<td>Intermediate Break LOCA</td>
<td>15.6.5.1.2</td>
<td>-</td>
<td>-</td>
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<tr>
<td>57</td>
<td>200 cm² LOCA cold</td>
<td>15.6.5.1.2.1</td>
<td>CSA/CBA</td>
<td>DBA</td>
</tr>
<tr>
<td>58</td>
<td>LOCA in PRZ Surge-Line</td>
<td>15.6.5.1.2.2</td>
<td>CSA</td>
<td>DBA</td>
</tr>
<tr>
<td>59</td>
<td>0.1A LOCA cold with Sump Swell Operation</td>
<td>15.6.5.1.2.3</td>
<td>CSA/RCA/CBA</td>
<td>DBA</td>
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<tr>
<td>60</td>
<td>0.1A LOCA cold with Sump Swell Operation</td>
<td>15.6.5.1.2.4</td>
<td>QA</td>
<td>DBA</td>
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<tr>
<td>61</td>
<td>Large Break LOCA</td>
<td>15.6.5.1.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>62</td>
<td>2A LOCA cold (DEGB. Different Break Sizes and Positions are investigated)</td>
<td>15.6.5.1.3.1</td>
<td>CSA/RCA/CBA</td>
<td>SBDBA</td>
</tr>
<tr>
<td>63</td>
<td>2A LOCA hot</td>
<td>15.6.5.1.3.2</td>
<td>CSA/CBA</td>
<td>SBDBA</td>
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<tr>
<td>64</td>
<td>Moderator LOCA</td>
<td>15.6.5.2</td>
<td>-</td>
<td>-</td>
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<tr>
<td>65</td>
<td>50 cm² Small Leak in Moderator Suction Line</td>
<td>15.6.5.2.1</td>
<td>CSA</td>
<td>DBA</td>
</tr>
</tbody>
</table>

83 NPP Scenarios
The Atucha-2 NPP

RELAP5-3D – Calculation of Temperatures, Pressures, Mass flows etc
Multiple Timesteps inside “Control-timestep”

Ovars:
- Temperatures
- Pressures
- Massflows

DRIVER-PROGRAM

Ivars:
- Valve positions
- Pumps on/off
- PRZ Heaters & Spray

DYNETZ – calculation of Signals from Control System
2011-2012 Activities

- LOCA recalculation
- Use of internal coupling solution for I&C (developed by NA-SA)
- Qualification
- Consolidate data bases (QA related)
- Visualization
Facility and experiments used in qualification activity related to CNA2 project:

<table>
<thead>
<tr>
<th>Experimental Test</th>
<th>Transient Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSB-VVER T#3</td>
<td>Stuck open PRZ safety valve</td>
</tr>
<tr>
<td>PSB-VVER T#5</td>
<td>Main Steam Line Break + SGTR</td>
</tr>
<tr>
<td>LOBI A2-81</td>
<td>100 cm² CL LOCA (0.7%)</td>
</tr>
<tr>
<td>SPES SP-SB-04</td>
<td>200 cm² CL LOCA (4.2%)</td>
</tr>
<tr>
<td>LOBI A1-83</td>
<td>0.1 A CL LOCA</td>
</tr>
<tr>
<td>LOBI BT-15</td>
<td>Loss of one MFW pump without starting of the reserve pump</td>
</tr>
<tr>
<td>LOFT L2-5</td>
<td></td>
</tr>
<tr>
<td>LOBI A1-06</td>
<td>2A CL LOCA</td>
</tr>
<tr>
<td>UPTF 05</td>
<td></td>
</tr>
</tbody>
</table>

Correspondence with FSAR scenarios
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
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
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)
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.
Structure and Sample, RDS-Facility

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

### SCRED main steps: RDS-Facility

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Evaluation</th>
<th>Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer rod bundle diameter</td>
<td></td>
<td>1.075 $\times$ 10$^2$</td>
<td>m</td>
</tr>
<tr>
<td>Barrel inside diameter</td>
<td></td>
<td>1.98 $\times$ 10$^{-5}$</td>
<td>m</td>
</tr>
<tr>
<td>Barrel outside pipe diameter</td>
<td></td>
<td>2.08 $\times$ 10$^{-4}$</td>
<td>m</td>
</tr>
<tr>
<td>Number of rod bundle</td>
<td>64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>2015 mm</td>
<td>2.343 m</td>
<td>Drawn 13</td>
</tr>
<tr>
<td>Elevation change</td>
<td>2015 mm</td>
<td>2.015 m</td>
<td></td>
</tr>
</tbody>
</table>

| Flow area                               |            | 2.498 $\times$ 10$^2$ | m$^2$   | Drawn 13 |
| Inside surface area                     |            | 1.457428 m$^2$       |         |         |
| Outside surface area                    |            | 2.119866 m$^2$       |         |         |
| Volume                                  |            | 2,498,102.2343 m$^3$ = 5,833,289.22 m$^3$ | m$^3$   |         |
| Pressure loss coefficient               | Expansion 307 to 308 |                 |         | Tab. 4.2 |
|                                          | $k_{ouf}=0.5$ |                 |         |         |
|                                          | $k_{en}=1$   |                 |         |         |

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
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
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.

<table>
<thead>
<tr>
<th>#</th>
<th>QUANTITY</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tot. No. of HYDR volumes</td>
<td></td>
<td>319</td>
</tr>
<tr>
<td>2</td>
<td>Tot. No. of HYDR junctions</td>
<td></td>
<td>378</td>
</tr>
<tr>
<td>3</td>
<td>Tot. No. of HYDR subvolumes in the core</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Tot. No. of heat structures</td>
<td></td>
<td>314</td>
</tr>
<tr>
<td>5</td>
<td>Tot. No. of mesh points in the heat structures</td>
<td></td>
<td>3310</td>
</tr>
<tr>
<td>6</td>
<td>Tot. No. of core active structures (radial x axial meshes)</td>
<td>17 x 6</td>
<td></td>
</tr>
</tbody>
</table>
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

![Graph showing pressure over time for different scenarios](image)
MASLWR: validation activities

RELAP5-3D SP-3 blind calculation

Core power

Primary side mass flow

Core inlet/outlet temperature

Sec.side steam outlet temperature

GRNSPG is involved in many OECD projects

Recent (on-going) activities with Relap5-3D

- Oskarshamn benchmark
- Kalinin 3 benchmark
- 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
**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
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SS (Experiment)</th>
<th>SS (Calculation)</th>
<th>Deviation (%)</th>
<th>Transient (Experiment)</th>
<th>Transient (Calculation)</th>
<th>Deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power, MW</td>
<td>2970.00</td>
<td>2970.00</td>
<td>0.00</td>
<td>1996.00</td>
<td>2017.00</td>
<td>1.05</td>
</tr>
<tr>
<td>PRZ level, m</td>
<td>8.60</td>
<td>8.69</td>
<td>1.03</td>
<td>7.99</td>
<td>7.82</td>
<td>-</td>
</tr>
<tr>
<td>Average heating in the reactor core</td>
<td>29.03</td>
<td>28.77</td>
<td>0.87</td>
<td>22.38</td>
<td>22.55</td>
<td>0.75</td>
</tr>
<tr>
<td>°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRZ level, m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Average heating in the reactor core</td>
<td>28.77</td>
<td>28.77</td>
<td>0.87</td>
<td>22.38</td>
<td>22.55</td>
<td>0.75</td>
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<tr>
<td>°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SG #1 pressure, MPa</td>
<td>6.26</td>
<td>6.29</td>
<td>0.47</td>
<td>6.02</td>
<td>5.98</td>
<td>-0.66</td>
</tr>
<tr>
<td>SG #2 pressure, MPa</td>
<td>6.29</td>
<td>6.30</td>
<td>0.15</td>
<td>6.27</td>
<td>6.20</td>
<td>-1.11</td>
</tr>
<tr>
<td>SG #3 pressure, MPa</td>
<td>6.25</td>
<td>6.28</td>
<td>0.48</td>
<td>6.23</td>
<td>6.22</td>
<td>-0.16</td>
</tr>
<tr>
<td>SG #4 pressure, MPa</td>
<td>6.24</td>
<td>6.31</td>
<td>1.12</td>
<td>6.16</td>
<td>6.14</td>
<td>-0.32</td>
</tr>
<tr>
<td>Coolant flow rate in loop #1, kg/s</td>
<td>4635.00</td>
<td>4635.00</td>
<td>0.00</td>
<td>-1530.00</td>
<td>-1883.00</td>
<td>23.07</td>
</tr>
<tr>
<td>Coolant flow rate in loop #2, kg/s</td>
<td>4639.00</td>
<td>4635.00</td>
<td>-0.09</td>
<td>5145.00</td>
<td>5288.96</td>
<td>2.72</td>
</tr>
<tr>
<td>Coolant flow rate in loop #3, kg/s</td>
<td>4550.00</td>
<td>4552.00</td>
<td>-0.04</td>
<td>5083.00</td>
<td>5120.80</td>
<td>0.72</td>
</tr>
<tr>
<td>Coolant flow rate in loop #4, kg/s</td>
<td>4550.00</td>
<td>4557.00</td>
<td>0.15</td>
<td>5200.00</td>
<td>5270.36</td>
<td>1.35</td>
</tr>
<tr>
<td>Total coolant flow rate, kg/s</td>
<td>18340.00</td>
<td>18379.00</td>
<td>0.21</td>
<td>13900.00</td>
<td>13794.10</td>
<td>-0.08</td>
</tr>
<tr>
<td>CL coolant temp in loop #1</td>
<td>288.00</td>
<td>287.90</td>
<td>0.03</td>
<td>284.90</td>
<td>284.48</td>
<td>-0.14</td>
</tr>
<tr>
<td>CL coolant temp in loop #2</td>
<td>287.80</td>
<td>288.00</td>
<td>0.07</td>
<td>287.40</td>
<td>287.18</td>
<td>-0.08</td>
</tr>
<tr>
<td>CL coolant temp in loop #3</td>
<td>287.60</td>
<td>289.80</td>
<td>0.76</td>
<td>288.00</td>
<td>289.84</td>
<td>0.66</td>
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<tr>
<td>CL coolant temp in loop #4</td>
<td>287.50</td>
<td>287.90</td>
<td>0.14</td>
<td>284.90</td>
<td>283.85</td>
<td>-0.36</td>
</tr>
<tr>
<td>HL coolant temp in loop #1</td>
<td>317.40</td>
<td>316.70</td>
<td>-0.22</td>
<td>276.90</td>
<td>273.17</td>
<td>-1.36</td>
</tr>
<tr>
<td>HL coolant temp in loop #2</td>
<td>317.40</td>
<td>317.00</td>
<td>-0.13</td>
<td>311.70</td>
<td>311.77</td>
<td>0.02</td>
</tr>
<tr>
<td>HL coolant temp in loop #3</td>
<td>316.40</td>
<td>318.20</td>
<td>0.57</td>
<td>313.60</td>
<td>315.90</td>
<td>0.73</td>
</tr>
<tr>
<td>HL coolant temp in loop #4</td>
<td>317.20</td>
<td>316.80</td>
<td>-0.13</td>
<td>304.01</td>
<td>300.94</td>
<td>-1.00</td>
</tr>
</tbody>
</table>
K-3 BENCHMARK: Selected results

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)
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