Severe accident phenomena assessment for VVER 1000 (V320) spent fuel pool

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BULGARIAN NUCLEAR ENERGY – NATIONAL, REGIONAL AND WORLD ENERGY SECURITY
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OUTLINE

- Goals and scope of the project
- SFP of VVER-1000 (V320) – layout
- MELCOR 2.1 model of SFP for VVER-1000 (V320)
- Scenarios and boundary conditions
- Initial conditions for the SFP
- Spreading areas
- Results
- Conclusions
Goals of the Project

- Severe accident phenomena analysis
- Cliff-edge effects identification
- Containment integrity challenges
- Radioactive releases paths to the environment and source term
- Assessment of doses on the site and up to the 30 km zone border
- Effectiveness of different strategies on stopping of SA progression or mitigation of the consequences
Scope of the Project

- Bounding scenarios for the most conservative IE and initial conditions
- Sensitivity analyses with application of strategies with water injection in the SFP at different moment of the accident progression
- Calculation of the accident progression and consequences (doses)
SFP of VVER-1000 (V320) – layout (part 1)

Transportation cask pit
Pool TG21B04

Spent fuel pools
Pool TG21B02
Pool TG21B01
Pool TG21B03

Reactor Pit
Revision Shafts
Pool TG21B05
Pool TG21B06

SFP positioning in the containment
SFP of VVER-1000 (V320) – layout (part 2)

Nodalization scheme of revision shafts, wet refueling shaft, transportation cask pit and drainage lines
SFP of VVER-1000 (V320) – layout (part 3)

Fuel Assembly

Rack

Supports

Upper supporting plate

Lower supporting plate

SFP Rack for VVER-1000 (V320)
MELCOR 2.1 model of SFP for VVER-1000 (V320)

The MELCOR 2.1 model for the analysis consists of the following parts:

- Containment model – the same of for the reactor SA analyses with slight modifications

- SFP pools model (TG21B01-TG21B06, including drainages and wet refueling shaft)

- Primary side model (reactor without internals and 4 loops which are lumped into a single loop)
MELCOR 2.1 model of SFP for VVER-1000 (V320) – part 1

Volume above the fuel assemblies
FA test channels

Fuel and fuel bypasses volume

Volume below the SFP supporting plates

VVER 1000 (V320) spent fuel pools (three pools with FA are separately modeled) – 9 radial rings for the COR package, 36 CV
CAV package nodalization (6 cavities modeled – all possible ways for corium transfer are considered)
### Scenarios and boundary conditions

<table>
<thead>
<tr>
<th>Scenario</th>
<th>TBO</th>
<th>LOCA from TG21B02 (5 m³/h)</th>
<th>CONT isolation (2h after 70°C in SFP)</th>
<th>CONT venting system</th>
<th>SFP Injection</th>
<th>SFP Injection onset</th>
<th>SFP injection mass flow rate, m³/h</th>
<th>SFP injection sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario 1 (base case)</strong></td>
<td>Yes</td>
<td>No</td>
<td>Manual</td>
<td>No</td>
<td>No</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Scenario 2</strong></td>
<td>Yes</td>
<td>No</td>
<td>Manual</td>
<td>No</td>
<td>No</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Scenario 3 (base case)</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Manual</td>
<td>No</td>
<td>No</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>Yes</td>
<td>Yes</td>
<td>Manual</td>
<td>No</td>
<td>Yes</td>
<td>at MCCI onset</td>
<td>45</td>
<td>TG discharge --&gt; TG21B01 --&gt; TG21B02</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>Yes</td>
<td>Yes</td>
<td>Manual</td>
<td>Yes</td>
<td>Yes</td>
<td>When corium relocates onto lower supp. Plate in B02</td>
<td>45</td>
<td>TG discharge --&gt; TG21B01 --&gt; TG21B02</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>Yes</td>
<td>Yes</td>
<td>Manual</td>
<td>No</td>
<td>Yes</td>
<td>4h after 98°C in SFP</td>
<td>45</td>
<td>TG discharge --&gt; TG21B01 --&gt; TG21B02</td>
</tr>
<tr>
<td>Scenario 7</td>
<td>Yes</td>
<td>Yes</td>
<td>Manual</td>
<td>No</td>
<td>Yes</td>
<td>4h after 98°C in SFP</td>
<td>45</td>
<td>TQ13D01 discharge (HPI pump) --&gt; Primary --&gt; B03 --&gt; B01 --&gt; B02</td>
</tr>
<tr>
<td>Scenario 8</td>
<td>Yes</td>
<td>Yes</td>
<td>Manual</td>
<td>No</td>
<td>Yes</td>
<td>4h after 98°C in SFP</td>
<td>45</td>
<td>TQ13D01 discharge (HPI pump) and 3 out of 4 HA --&gt; Primary --&gt; B03 --&gt; B01 --&gt; B02</td>
</tr>
<tr>
<td>Scenario 9**</td>
<td>Yes</td>
<td>Yes</td>
<td>Manual</td>
<td>No</td>
<td>Yes</td>
<td>At gap release</td>
<td>45</td>
<td>Wet ref. shaft , B05,B06--&gt;SFP TQ13D01 discharge (HPI pump) --&gt; Primary --&gt; B05,B06 --&gt; SFP</td>
</tr>
</tbody>
</table>

*TF penetrations are assumed to remain intact

**Initial level in wet refueling shaft 35.9 m
Initial conditions for the SFP (Scenario 1 – Scenario 8)

In the analysis SFP is fully loaded with TVSA-12 FA
Spreading areas in compartments GA308/GA310

- GA301: 33.6 m²
- GA302: 47.5 m²
- GA308: 30.74 m²
- GA310: 84.55 m²
- GA301 penetrations
- GA310 penetrations

Transport hatch

Spreading area ~400 m²

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### Results – Summary information

<table>
<thead>
<tr>
<th>Scenario</th>
<th>TBO from 802 (5 m³/h)</th>
<th>LOCA</th>
<th>Containment pressure, MPa</th>
<th>Acceptance Criterion: 0.49</th>
<th>Containment temperature, degC</th>
<th>Acceptance Criterion: 150</th>
<th>H₂ max vol. conc. %</th>
<th>Acceptance Criterion: H₂/O₂/Steam= 4/5/55</th>
<th>CONT Failure</th>
<th>SFP inj. success</th>
<th>H₂/CO total mass, kg</th>
<th>Time for containment failure, h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1 (base case)</td>
<td>Yes</td>
<td>No</td>
<td>0.24</td>
<td>110</td>
<td>4.26/13.2/32.3</td>
<td>YES</td>
<td>717/8931</td>
<td>22:00</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Scenario 2*</td>
<td>Yes</td>
<td>No</td>
<td>0.49</td>
<td>158</td>
<td>4.26/13.2/32.3</td>
<td>YES</td>
<td>800/10742</td>
<td>52:20 * (acceptance criterion is violated)</td>
<td></td>
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<td>Scenario 3 (base case)</td>
<td>Yes</td>
<td>Yes</td>
<td>0.226</td>
<td>105</td>
<td>3.22/13/29</td>
<td>YES</td>
<td>683/9991</td>
<td>20:12</td>
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<td>Scenario 4</td>
<td>Yes</td>
<td>Yes</td>
<td>0.182</td>
<td>94</td>
<td>3.22/13/29</td>
<td>YES</td>
<td>NO</td>
<td>563/7397</td>
<td>19:14</td>
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<td>Scenario 5</td>
<td>Yes</td>
<td>Yes</td>
<td>0.392</td>
<td>134</td>
<td>3.22/13/29</td>
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<td>YES</td>
<td>221/-</td>
<td>-</td>
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<td>Scenario 6</td>
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<td>Yes</td>
<td>0.149</td>
<td>85</td>
<td>0.0</td>
<td>NO</td>
<td>YES</td>
<td>+/-</td>
<td>-</td>
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<td>Scenario 7</td>
<td>Yes</td>
<td>Yes</td>
<td>0.186</td>
<td>116</td>
<td>2.9/14/28</td>
<td>YES</td>
<td>NO</td>
<td>552/7509</td>
<td>20:38</td>
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<td>Scenario 8</td>
<td>Yes</td>
<td>Yes</td>
<td>0.257</td>
<td>144</td>
<td>3.1/13.5/29</td>
<td>NO</td>
<td>YES</td>
<td>+/-</td>
<td>-</td>
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<td>Scenario 9</td>
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<td>Yes</td>
<td>0.41</td>
<td>135</td>
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<td>YES</td>
<td>+/-</td>
<td>-</td>
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</tbody>
</table>

* TF penetrations are assumed to remain intact for Scenario 2
For Scenario 3 operator actions are not considered
For Scenario 5, SFP injection is assumed at the moment of corium relocation onto the SFP lower supporting plate. The injection flow rate is 45 m³/h.
Doses

- Only scenarios with Cs-137 above 30 TBq are analyzed in radiological consequences
- Results:
  - Individual annual effective doses of irradiation on the NPP site are in the range of $2.37 \div 5.95E+01$ Sv
  - Individual annual effective doses of irradiation on the 2 km zone are in the range of $6.15E-01 \div 1.845E+01$ Sv
  - Individual annual effective doses of irradiation on the 30 km zone are in the range of $7.76E-03 \div 6.39E-02$ Sv
- For all scenarios the criterion of 50 mSv is violated
- Sheltering, iodine prophylaxis and evacuation are needed
Conclusions

- The main vulnerability for the containment integrity are the penetrations of TF system in compartment GA308
- Hydrogen burn is not a threat for the containment integrity
- The threat of static containment overpressure is possible at the later phase of the SA progression if containment bypass through TF penetrations does not occur (Scenario 2)
- The protection of TF penetrations guarantee that molten corium is retained into the containment
- For all scenarios with containment failure individual annual effective doses of irradiation is above the required criterion, i.e. consequences are unacceptable
Recommendations

- Analyses of different means for TF tubes protection
- Equalizing the heat decay in different pools – gives more time for strategy application
- For avoiding failure of the concrete bottom of pool TG21B02 is recommended strategies for SFP injection to be implemented before MCCI onset with minimal flow rate of 45 m³/h
- Additional analyses and possible change the SAMG entry point
- Development of computational aids for available time of strategy application based on the different decay heat in the pools
- Analyze the possibility of changing the level measurement in the pools
THANK YOU!
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