Analysis of loss of water in the Spent Fuel Pools of Ignalina NPP after reactor shutdown

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Outline

• Introduction
• Spent Fuel Storage and Handling System
• RELAP/SCDAPSIM analysis of loss of water in SFP after the shutdown of reactor
• ASTEC analysis of loss of water in SFP after the shutdown of reactor
• Analysis of loss of water accident in SFP three years after the shutdown of reactor
• Conclusions
At the Ignalina NPP two RBMK-1500 Russian design channel-type graphite-moderated boiling water reactors are shut down for decommissioning (31 December of 2004 and 31 December of 2009).

The reloaded from the RBMK-1500 reactor FA remain in the pool for at least a year, after which they may be removed to be cut in a “hot” cell.

The two fuel bundles (each 3.5 m long placed one above the other) are separated and placed into the special shipping casks.
• The shipping casks with SFA are stored in pools until loading into protective casks CASTOR or CONSTOR for transportation to dry SF storage facility.
• After final shutdown, the total amount of SFA was about 22000 (about 2500 tons).
• The last SFA was unloaded from the reactor on 25 February 2018.
• The most challenging consequences for the SFP can occur in the case of loss of heat removal.
• The heat removal from the SFAs in SFP can be lost due to failure of heat removal system or in the case of uncompensated leakage of water from SFPs.

• The analysis of loss of water was performed using RELAP/SCDAPSIM and ASTEC computer codes.

• Two cases were analysed:
  – Safety evaluation of SFP at Ignalina NPP just after the shutdown of Unit 2 reactor (situation on January 01 of 2010).
  – Situation after three years after the permanent shutdown of Unit 2 reactor of Ignalina NPP.
• Spent fuel storage and handling system is designed to implement the following basic processes:
  – Holding & storing SF extracted from the reactor (prior to cutting process, cooling period is at least for 1 year);
  – Cutting SFA into fuel bundles and placing them into 102 pcs. shipping casks;
  – Holding 102 pcs. shipping casks with cut FA assemblies in storage pools;
  – Transporting SF outside from the units (after cooling in pools for at least 5 years) to the dry storage facility.

• Dry Spent Fuel Storage in the Casks during 50 years.
Spent Fuel Storage and Handling System of each reactor unit consists of 12 pools:

- Two pools (Compartments 236/1, 236/2) for cooling uncut SF extracted from the reactor;
- Five pools (Compartments 336, 337/1,2, 339/1,2) used for storing SF in 102 pcs casks after cutting;
- One pool for collecting SFA prepared for cutting, cutting hanger from SFA, transporting SFA to the hot cell and 102 pcs casks in the hot cell and backward to pools (Compartment 234);
Spent Fuel Storage and Handling System (3)

- Two pools (Compartments 338/1, 338/2) to perform operations to load the shipping casks with the FA into the transport casks and store the 102 placed shipping casks;
- Transport corridor (Compartment 235) intended to transport SFA and shipping casks loaded with spent fuel assemblies between the pools;
- Transport corridor (Compartment 157) intended to transport fresh fuel and reactor assemblies from the fresh fuel assembly preparation bay to the reactor and return spent fuel and reactor assemblies from the reactor to the storage pools.
Spent Fuel Storage and Handling System

rooms 157, 235 - transport corridor
room 234 - transport corridor in the cutting bay
rooms 236/1,2 - spent fuel assembly storage pools
rooms 336, 337/1,2, 339/1,2 - storage pools for 102 pcs. casks with cuttec
rooms 338/1,2 - pools for loading transport container
room 625 - hot cell
room 627 - control room of hot cell
rooms 513, 0101, 046, 047 - FFLA
RELAP/SCDAPSIM analysis of loss of water in SFP after the shutdown of reactor (1)

- For the analysis single compartment 336 with the highest decay heat load (171.6 kW) selected with 1428 SFA.
- Remaining compartments of SFP are modelled as single compartment.
- Adiabatic condition on outer surface of wall.
RELAP/SCDAPSIM analysis of loss of water in SFP after the shutdown of reactor (2)

Temperatures of fuel and SFP structures

At the time moment 780 h exothermic steam – zirconium oxidation reaction starts.
RELAP/SCDAPSIM analysis of loss of water in SFP after the shutdown of reactor (3)

Pressure inside the fuel rods

Heat transfer coefficient to the pool walls

At the time moment 822 h - rupture of fuel rods claddings and release of gasses to the pool.
RELAP/SCDAPSIM analysis of loss of water in SFP after the shutdown of reactor (4)

Heat transfer in the 336 compartment

Sum of heat dissipated in the walls and removed by air in the room above SFP less than decay heat generated in SFA

Temperature of spent fuel increases

Heat transfer in the 336 compartment

Residual decay heat of SFAs

Start of steam - zirconium reaction

Through the cover of pool
To the wall of pool
Total
ASTEC analysis of loss of water in SFP after the shutdown of reactor (1)

- For the analysis single compartment 336 with the highest decay heat load (171.6 kW) selected with 1428 SFA.
- Adiabatic condition on outer surface of wall.
- SFP cover plate not modelled.
• Processes modelled:
  – Radial conduction between fuel and cladding;
  – Axial, radial, azimuthal conduction inside each modelled element;
  – Convective heat exchange;
  – Heat exchanges between corium layers and with wall;
  – Claddings oxidation;
  – \( \text{UO}_2 \) and \( \text{ZRO}_2 \) dissolution by liquid Zr;
  – Oxidation of U-Zr-O magma;
  – Radial movement of materials;
  – Decanting in lower part of pool;
  – 2D movement of magma;
  – Corium slumping, fragmentation;
  – Fission products and structural materials transport;
  – …
ASTEC analysis of loss of water in SFP after the shutdown of reactor (3)

- t= 100 s – initiation of water leakage in the SFP;
- t= 2.2 h – fuel uncovering and heat up in air starts;
- t= 7.5 h – all SFAs are fully uncovered;
- t= 10.3 h – water level decreases down to the bottom of SFP;
- t= 416.88 h - first cladding creep rupture;
- t= 416.88 h - start of FPs release from fuel pellets (200 s later from first cladding rupture);
- t= 877.26 h - first material slump of SFP floor;
- t= 964.34 h – calculation terminated after melt through one layer of concrete wall.

Maximal fuel temperature

Fuel temperature increases until reaches melting temperature of concrete wall (~1527 °C)
ASTEC analysis of loss of water in SFP after the shutdown of reactor (4)

Hydrogen generation

Only highly volatile fission products released:
- Near 100% were released Ag, Br, Cs, Cu, I, Kr, Rb and Xe.
- About 29% - Se and Te.
- About 52% - Sb.
Analysis of loss of water in SFP three years after the shutdown of reactor (1)

- ASTEC V2.0R2 single pool model with 4 different fuel rod groups.
- The total decay heat in the SFP of Unit 2 three years after shutdown - 810 kW.
- Heat transfer through the concrete wall.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Fuel rod groups in the model</th>
<th>SFA decay heat, kW</th>
<th>Amount of SFAs in group</th>
<th>Group power, kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFAs in compartment “236/2”</td>
<td>ROD1</td>
<td>0.153</td>
<td>166</td>
<td>~25.4</td>
</tr>
<tr>
<td>SFAs in “236/2” compartment</td>
<td>ROD2</td>
<td>0.122</td>
<td>1182</td>
<td>~144.20</td>
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<td>SFAs in “236/1” and “234” compartment</td>
<td>ROD3</td>
<td>0.122</td>
<td>892</td>
<td>~108.82</td>
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<tr>
<td>SFAs in shipping casks</td>
<td>ROD4</td>
<td>0.9387</td>
<td>5661</td>
<td>~531.40</td>
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<tr>
<td>Total:</td>
<td></td>
<td>7901</td>
<td></td>
<td>~810</td>
</tr>
</tbody>
</table>
Analysis of loss of water in SFP three years after the shutdown of reactor (2)

Fuel temperature increases, until reaches about 400 °C

Decay heat from the spent nuclear fuel is removed by air and by conduction through walls of SFP building.
Conclusions

- For the analysis of the loss of water in the SFPs models were developed using the RELAP/SCDAPSIM and ASTEC codes.
- Calculation, performed for the compartment with the highest decay heat load covered by the steel sheets, shows that the temperature of fuel is continuously increasing. But the heat up process is very slow after total loss of water in the pool. Thus, the operators have enough time to find the alternative means for the cooling of SFP.
- The preliminary ASTEC analysis for the situation three years after the permanent shutdown of Unit 2 showed that SFAs can be cooled by the air circulation.
Thank you for the attention

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