Autoswitch: Smooth Transition from Standard Simulated Plant Operation to Severe Accident Conditions

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Topics

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MAAP5 is an Electric Power Research Institute (EPRI) software program that performs severe accident analysis for nuclear power plants including assessments of core damage and radiological transport. A valid MAAP5 license to MAAP5 from EPRI for customer’s use of MAAP5 is required prior to a customer being able to use deploy MAAP5 with Licensee’s simulator products. EPRI (www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. As an independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI does not endorse any third party products or services. Interested vendors may contact EPRI for a license to MAAP5.
Introduction

• The Fukushima-Daiichi accident prompted many utilities to examine the role of severe accidents in their training programs, including on their real-time operator training simulators such that plant personnel are well trained on how to cope with severe accidents.

• In general, most of the existing full scope simulators
  – Cannot provide severe accidents training
  – Have simplified spent fuel pool models
  – Have inadequate electrical models to support training on degraded battery conditions during Station Blackout conditions (SBO)

• L3 MAPPS’ first SAS deployment on a real-time operator training simulator was in 2000.
L3 MAPPS SAS Technical Solution Overview

• Based on Electric Power Research Institute’s (EPRI) Modular Accident Analysis Program (MAAP) Severe Accident Simulation (SAS) fully integrated into L3 MAPPS’ Orchid® simulation environment

• Multiple implementations possible
  – Full Scope Simulator
  – Engineering Simulator
  – Classroom Simulator
  – Standalone SAS Simulator

• Several MAAP versions can be implemented such as MAAP5-PWR, MAAP5-BWR, MAAP4-CANDU, MAAP5-CANDU, etc.
L3 MAPPS SAS Technical Solution Overview

• MAAP Capabilities
  – Degraded Reactor Core Conditions
    ▪ Fuel Melting
    ▪ Cladding Oxidation
    ▪ Hydrogen Generation
    ▪ Vessel Failure
  – Containment Failure
  – Fission Product Release
• Expand Existing Simulator Capabilities
  – Beyond Design Basis Accidents (BDBAs)
  – Severe Accidents (SAs)
L3 MAPPS SAS Technical Solution Overview

• Equipped with 2-D and 3-D animated and interactive visualizations of
  – Reactor Vessel
  – NSSS
  – Containment Building
  – Spent Fuel Pool

• Provides plant personnel (i.e. operators, emergency response organization, engineers, management, etc.) with additional insight into the behavior of the plant during severe accidents

• Autoswitch feature to transition seamlessly from L3 MAPPS’ standard models to SAS models when the hottest fuel temperature exceeds a pre-defined temperature*

*Does not apply to Standalone SAS Simulator
<table>
<thead>
<tr>
<th>Location</th>
<th>SAS Training Simulator</th>
<th>Service Dates</th>
<th>MAAP Integrations</th>
<th>Integration Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krško (Slovenia) FSS</td>
<td>Nuklear Elektrarna Krško</td>
<td>2000</td>
<td>Integration of MAAP4: 2000</td>
<td>Integration of MAAP5: 2017</td>
</tr>
<tr>
<td>Olkiluoto 3 (Finland) FSS</td>
<td>TVO</td>
<td>2011</td>
<td>EPR-specific version (MAAP4-ANP3)</td>
<td>Integration of MAAP4-ANP3: 2Q18 (ongoing)</td>
</tr>
<tr>
<td>Ling Ao Phase II (China)</td>
<td>中广核 CGN</td>
<td>2011</td>
<td>Integration of MAAP5: 2013</td>
<td>Integration of MAAP5 with Autoswitch: 2Q18 (ongoing)</td>
</tr>
<tr>
<td>Susquehanna 1 (USA) FSS</td>
<td>TALEN Energy</td>
<td>1990; currently being upgraded by L3 MAPPS</td>
<td>Integration of MAAP5: 1Q18 (ongoing with simulator upgrade)</td>
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<tr>
<td>PWR SAS Training Simulator</td>
<td>原子力規制委員会 Nuclear Regulation Authority</td>
<td>2016</td>
<td></td>
<td>South Texas Project (USA) FSS</td>
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<tr>
<td>South Texas Project (USA)</td>
<td>STP</td>
<td>1996; upgraded to latest Orchid® in 2016</td>
<td>Integration of MAAP5: 2016 (delivered with Orchid® upgrade)</td>
<td></td>
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<tr>
<td>Wolsong 1 (Korea) FSS</td>
<td>KHP</td>
<td>2018</td>
<td>Integration of MAAP4-CANDU: 2Q18 (ongoing with FSS)</td>
<td></td>
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Autoswitch Mechanism

• Before Switch Point, L3 MAPPS standard models are active
• MAAP5 spent fuel pool model is used for all conditions
• MAAP5 models (reactor core, NSSS and containment) are initialized when the hottest fuel temperature reaches 750 °C (Trigger Point)
• Transition Zone is between 750 °C and 775 °C to allow the MAAP5 models to stabilize and match the L3 MAPPS models
• Seamless switchover occurs when the hottest fuel temperature reaches 775 °C (Switch Point)
**Autoswitch Setpoints Selection (PWR)**

- **Why did L3 MAPPS choose 775 °C as the Switch Point?**
  - Control rods are made of boron, silver (Ag), indium (In) and cadmium (Cd) → Ag-In-Cd
  - Control rods have the lowest melting point (1,050 °K or 777 °C) of all material present in the reactor vessel
  - At this temperature, the plant values of L3 MAPPS standard models and MAAP5 models match relatively well to ensure a bumpless transition

- **Why did L3 MAPPS choose 750 °C as the Trigger Point?**
  - Allow MAAP5 models to initialize and stabilize
  - At this temperature, the plant values of L3 MAPPS standard models and MAAP5 models match relatively well

*source: MAAP5.04 documentation*
Test Case #1: Large Break LOCA without Safety Injection

Where is the switchover point?
Test Case #1: Large Break LOCA without Safety Injection
Test Case #2: Station Blackout (SBO)

Where is the switchover point?
Test Case #2: Station Blackout (SBO)
BWR SAS – Reactor Core Vessel 3-D Visualization
BWR SAS – Primary Containment 3-D Visualization
BWR SAS – Spent Fuel Pool 3-D Visualization
2-D Visualization - Offsite Dose

Meteorological and Environmental Radiation display

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>80m Wind Speed</td>
<td>4.59 m/s</td>
</tr>
<tr>
<td>80m Wind Direction</td>
<td>246 Deg/dir</td>
</tr>
<tr>
<td>Atmospheric Pressure</td>
<td>1013.00 hpa</td>
</tr>
<tr>
<td>Rain gauge</td>
<td>0.1 mm</td>
</tr>
<tr>
<td>Atmospheric Stability</td>
<td>E</td>
</tr>
</tbody>
</table>
Examples of Severe Accident Simulator Implementations

Japan

China
Conclusions

• MAAP-based real-time SAS integrated with full scope simulators has been delivered by L3 MAPPS since 2000

• SAS demand is on the rise since the Fukushima-Daiichi nuclear accident

• L3 MAPPS offers PWR, BWR and CANDU SAS solutions

• The “Autoswitch” feature allows smooth transition from standard models to SAS models when the hottest fuel temperature exceeds a predefined temperature

• SAS supplemented with 2-D and 3-D visualizations for the reactor vessel, NSSS, containment and spent fuel pool help better understand severe accidents

• Offsite dose can also be included
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