Enhancing Human Reliability in Severe Accident Mitigation Through Advanced Expert Systems

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Agenda

- Company Introduction
- SAMG Challenges in Evaluation and Decision Making Process
- Evaluation and Decision Making Support Tools
- Strategy Implementation Support Tools
- Conclusions
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SE Company Introduction
Balanced and Environmental Friendly Generation Portfolio

SE Power Plants Map (2016)

SE Plants Key Figures (2016)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Gross capacity (MW)</th>
<th>COD</th>
<th>Expected Decommiss.</th>
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<tbody>
<tr>
<td><strong>A Nuclear</strong></td>
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<tr>
<td>Bohunice V2 unit 3</td>
<td>505</td>
<td>1984</td>
<td>2044</td>
</tr>
<tr>
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<td>2045</td>
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<td>470</td>
<td>1998</td>
<td>2058</td>
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<td>470</td>
<td>2000</td>
<td>2060</td>
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<td>Mochovce unit 3 (under construction)</td>
<td>519</td>
<td>2018</td>
<td>2078</td>
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<td>Mochovce unit 4 (under construction)</td>
<td>519</td>
<td>2019</td>
<td>2079</td>
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<td><strong>B Hydro</strong></td>
<td></td>
<td></td>
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<td>Pumped storage</td>
<td>916</td>
<td>Various</td>
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<tr>
<td>Run-of-river</td>
<td>736</td>
<td>Various</td>
<td>n.a.</td>
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<td><strong>C Thermal</strong></td>
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<td>Vojany plant I (black coal)</td>
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<td>1966</td>
<td>2035</td>
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<td>Nováky A (brown coal)</td>
<td>46</td>
<td>1953-66-2003</td>
<td>2035</td>
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<td>Nováky B (brown coal)</td>
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<td>1964-1976</td>
<td>2035</td>
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<td><strong>D Photovoltaic</strong></td>
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<tr>
<td>Vojany</td>
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<td>2011</td>
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</tr>
</tbody>
</table>

- **Slovenské elektrárne, a.s.** is an electric utility company based in Bratislava, Slovak Republic.
Slovak NPPs EBO and EMO

EBO Unit 3 = 107% = 505 MWe
EBO Unit 4 = 107% = 505 MWe

EMO Unit 1 = 107% = 470 MWe
EMO Unit 2 = 107% = 470 MWe
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Severe Accident Management Guidelines, not Procedures

- Uncertainties
- Initiating Event or Hazard
- SA Knowledge
- CR and ERO Response
- Plant Config

- Human Reliability
- SAMG
- Structure
- Technical Bases
- Analytical Support
Severe Accident Management
Evaluation and Decision Making Challenges

- Limited set of reliable instrumentation
- Limited guidance on weighing “pros” and “cons”
- Timeliness in specific situations (severe containment challenge, high dose rates,…)
- Elevated personnel stress levels
Severe Accident Management
SAMG Usage Lessons Learned

- No clear basis for weighing “pros” and “cons” of SAMG strategies
- Not sufficient level of detail for weighing “pros” and “cons” of SAMG strategies
- Too many uncertainties in plant evaluation result in decision making paralysis
- Different decisions for the same situation depending on personnel SAMG knowledge
Post-Fukushima SAMG Initiatives
Development of Enhanced SAMGs

**Pros**
- Enhanced human reliability
- Consistent decisions in SAM
- Rule based decision making tools
- Extended SAM technical basis

**Cons**
- Core heat removal
- Containment overpressurization
- On-site dose rates
- Containment atmosphere inertization
- Hydrogen production
- Hydrogen production
Enhanced SAMGs
What Should We Focus on Next?

Evaluation and Decision Making Consistency Main Achievements
- Extended SAM technical basis used to reassess SAM strategies
- Redefinition of key governing plant parameters (symptoms in decision trees)

Are Incorporated Changes Sufficient?
- Evaluation and decision making consistency achieved to some extent using more SAMG background assumptions
- Basic process of weighing pros and cons is not changed
- No generic specific tools to support SAMG usage developed so far
- Limited scope of guidance for weighing pros and cons remains
Examining the Enhancement of Human Reliability in Accident Conditions

**Generic Challenges**
- Elevated stress levels
- Proper decision making often limited in time
- Specific guidance to treat uncertainties in evaluation of plant status to support decision making not existing

**Main Areas in Need for Support**
- Plant status evaluation by TSC
  - Availability of SSCs
  - Plant parameter evaluation
- Accident management strategy recommendation
- SSC lineup for accident management strategy implementation
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Support Tool for SAMG Strategy Decision Making Addressing Main Challenges

Challenges Resulting from SAM and SAMGs
- Evaluation and quantification of negative aspects of SAM strategies
- Evaluation and quantification of positive aspects of SAM strategies
- Treatment of uncertainties in decision making
- Evaluations and decision making of different teams may result in implementation of quite opposite strategies
- Limited extent of field instrumentation

Systematic Approach in Uncertainties Treatment
- Quantitative and methodologically consistent support tool
- Deployment of data science techniques to analyze non-trivial conditions between plant parameters
- Deployment of data science techniques to predict plant behaviour
Support Tool for SAMG Strategy Decision Making
Pilot Study for Hydrogen Risk

Goal:
• Statistically robust model based assistance in accident conditions providing consistent solution recommendations.

Data & Input:
• MELCOR simulations of 128 accident scenarios.
• MELCOR parameters corresponding to plant monitoring sensors: pressure, temperature, water level, hydrogen and oxygen molar ratios.

Plant operator intervention:
• Sprays timing and duration.

Response:
• Hydrogen risk evaluated using $\text{H}_2\text{O} + \text{CO}_2 / \text{H}_2 + \text{CO}$ Breitung et al. diagram.
Containment Hydrogen Risk Decision Tree

Hydrogen molar ratio

CVH.X.4.856 < 0.035

OK
0.71 100%

> = 0.035

Water level

CVH.CLIQLEV.806 >= 7

OK
0.81 87%

< 7

Sprays duration

spraysWC < 29e+3

OK
0.99 98%

>= 29e+3

Low risk of flames/DDT in CTMT

High risk of flames/DDT in CTMT

flames/DDT
0.89 9%

flames/DDT
0.97 13%
- Hydrogen risk is not the same everywhere in containment.
- Hydrogen risk heatmap in containment MELCOR volumes for all accident scenarios allows to evaluate risk in corresponding containment compartments.

**Final Model:**
- Decision trees and risk heatmaps provide interpretable snapshots of parametric and spatial relationships.
- With random forest algorithm it was possible to achieve **94% accuracy** in predicting hydrogen risk conditions in containment at the end of containment spray interval using the monitoring of plant data input at the beginning of each spray interval.
- Methodology, model and visualizations courtesy of Inference Technologies [www.inferencetech.com](http://www.inferencetech.com).
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EOPs and SAMGs provide only strategies not particular SSC configurations directly linked with safety functions, what CMT does:

- All information about SSCs and system dependencies (cooling, electrical supply,…) stored at one place
- Direct solutions of setting up particular system and all of its dependent subsystems
- Computational aids help to prioritize individual steps in AM strategy

Quick assessment of the existence of necessary measures for the provision of safety functions:

- Possibility to systematically check for the plant robustness of safety functions provision under user defined IEs
- Gradual increase in the severity of IE allows one to search for potential cliff-edge effects
Configuration matrix tool – General Idea
SSC Availability Checking & Lineup Optimization

- Pumps flooded in room A, BUT tanks are operable and can be used
- It is possible to use pumps located in room B or room C
Configuration Matrix Tool Main Screen
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Enhancement of Human Reliability in SAM

- Human reliability in severe accident management can be extensively supported through advanced computerized systems
- SAMG evaluation and decision making support can benefit greatly from data-driven decision making tools developed using latest data science techniques
- Timely and effective implementation of selected SAMG strategies can be significantly supported with tools for rapid SSC line-up assessment
- Current state of the art of computer and data science allow the development and deployment of such tools
Thank You Very Much for Your Attention!