PRAMEA – probabilistic risk assessment (PRA) methods and applications

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Project overview

- PRAMEA is an umbrella project covering most of PRA
  - not included: some aspect of digitalized control system PRA, applied PRA in risk-informed in-service inspections of pipes

- Main objectives
  - Improve and develop methods for risk-informed decision making
  - Improve and develop PRA methods
  - Develop PRA knowledge and expertise in Finland
  - Foster international cooperation, import best practices to Finland

- Not included in this presentation
  - Use of human reliability analysis (HRA) outside of PRA
  - Dynamic PRA (analysis of dynamic flowgraph methodology)
  - Importance measures for operations involving schedule risks
Human Reliability Analysis (HRA) for advanced control rooms (ACR)

- The use of digital human-system interfaces (HSI)
  - Changes the working environment of the operator
  - Induces new tasks
  - Modifies the group dynamics and communication.
- Suggested effects on human reliability:
  - Improved crew performance and reduced workload
  - Declined primary task performance due to attention shift to interface management
  - Sub-optimal use of the HSI in high workload situations due to minimized capability to focus on interface management tasks
- Traditional HRA methods cannot properly address the new aspects introduced by digital HSI

Analogue conventional control room
- Paper-based procedures
- Hard-wired indicators/LCD displays
- Hard-wired/Analogue controls

Digitalised advanced control room
- Computer-based procedures
- Integrated information system
- Soft controls

Source: TVO
Human Reliability Analysis (HRA) for advanced control rooms (ACR) - Results

- Literature review
  - The effect of digital HSI on human behavior and reliability
  - Applicability of traditional HRA methods to digital HSI
  - HRA methods for digital HSI
  - U.S.NRC NUREG guidelines

- Analysis of performance shaping factors (PSF)
  - Appropriateness of commonly used PSFs in ACR settings
  - Human factor issues affecting performance in ACR
  - Overview of ways to assess effect of PSFs

- Safety benefit:
  - Better modelling of human reliability in ACR
  - Enables identification of safety weaknesses in ACR settings
Assessment of dependences in human reliability analysis (HRA)

- Many PRA scenarios include multiple human interactions
- Literature and case studies have been performed to summarise the state-of-the-art and to provide recommendations for PRA practitioners
- Finnish-Swedish collaboration
- First issue is to identify relevant dependences, e.g.
  - testing or maintenance of redundant equipment
  - multiple operator actions during accident scenario
- For quantification, tabulated values/formulas can be used:
  - No – Low – Medium – High – Full dependency
- Safety benefit: identification of potential human factors weaknesses at the plant, more realistic risk assessment

Example: LOCA during refuelling outage
Multi-unit PRA

- Previously PRA has only been performed for individual reactor units even though there are dependencies between the units

- A multi-unit PRA methodology has been outlined
  - Aims to estimate multi-unit core damage frequencies (or large early release frequencies) related to different multi-unit dependencies
  - Quantitative analysis aims to utilize existing single unit PRA models as much as possible
  - Identification, analysis, modelling and quantification of multi-unit dependencies
- Risk metrics, and required input data and supporting analyses have been considered in the report

- Safety benefit:
  - Analysis of multi-unit risks
Level 2 PRA analyses: release height and temperature, hydrogen explosions

- Developed in the IDPSA framework
- Factors affecting containment release height and temperature identified
  - Height affected by containment failure mode
    - Mostly isolation failures through doors, cable penetrations etc.
  - Chimney height in controlled releases
  - Temperature normally close to 100° C
    - Fires and explosions may rise T
- Hydrogen explosions studied
  - In BWR, may occur as a result of inerting failure, or during startup, shutdown or refuelling
- Safety significance: release height and temperature affect atmospheric dispersion
**Level 2 PRA development: Tight integration between the levels 1 and 2**

- PRA is most accurate when dependencies between levels 1 and 2 are modelled, and all the relevant information is passed from level 1 to level 2.

- Tight integration of PRA levels 1 and 2 was developed in FinPSA. The development focused on:
  1. How level 1 information is incorporated and utilised in level 2 models
  2. How level 1 accident sequences and basic events are seen in level 2 results

- FinPSA implementation is also verified and validated against Excel calculations.

- Safety benefit: More accurate level 2 results and improved trace back of level 2 results to level 1.
Nordic guidance for level 3 probabilistic safety assessment

- Main result of a Nordic cooperation project
  - Partners: Lloyd’s Register Consulting, ÅF consulting, Risk Pilot, VTT
- Main foci
  - Legal basis: Nordic regulatory framework
  - Standards, guidelines etc.
  - Risk metrics and safety criteria
  - Using data, handling countermeasures, presentation of results
- Main safety benefit: harmonization of analyses
A pilot of using integrated deterministic and probabilistic safety assessment in level 3 PRA

- Problem: level 3 analyses are tedious
- Solution: combine deterministic and probabilistic analyses in a probabilistic model
- Implementation: probabilistic analyses in an event tree model (FinPSA), deterministic analyses with ARANO

Safety benefits:
- enables the conduct of extensive analyses with reasonable effort
- provides a systematic risk picture
A review of dose assessment methods used recently

- Topic: population dose assessment methods used in major studies or modern software
  - VALMA, SILAM, RODOS, SOARCA study, UNSCEAR Fukushima study
- relatively little progress in last 20 years
- Safety analysis implications
  - Dose assessment could take human behaviour more accurately into account (behavioural simulation)
  - Dose assessment could be made physically more realistic (Monte Carlo simulation)
  - Dose assessment could use the result of more precise countermeasure analyses (traffic simulation in evacuation, structures of houses in shielding)
Portfolio Optimization for Risk-Informed Decisions

- Why portfolio optimization?
  - Prioritization based on standard risk-importance measures fails to account for costs
  - Component-based optimization leads to sub-optimal risk management plans

- Objectives
  - Develop methods for identifying combinations (portfolios) of risk management actions to minimize residual risks at different cost levels of risk management
  - Account for risk, cost of risk management and resource constraints simultaneously
  - Apply and evaluate methods to nuclear and other safety critical systems

- Challenges
  - Develop computationally tractable approaches for large systems
  - Using incomplete information when reliable parameter estimates are not available
Task 8.2: Achievements and future research

Completed applications
- Pipe inspections (c.f. RI-ISI)
  - Problem: Which pipes should be inspected, given incomplete information about failure probabilities and failure impacts?
  - Large-scale optimization of inspections of the sewerage network in Espoo
- Defence-in-depth
  - Problem: Which combinations of safety barriers are cost-effective in a system with event dependencies and multi-state failure behaviours?
  - Ongoing collaboration with an Italian industrial partner with interests in barrier optimization for occupational safety (modelled through Safety Integrity Levels)

Future research
- Optimizing portfolios of testing strategies
- Applying methodologies with Finnish industrial partners
- Building and solving time-dependent Defense-In-Depth models
Journal publications


Conference publications


The Airlock System prevents the dispersion of contaminants by keeping the pressure of the inside of the reactor vault lower than the outside pressure.

<table>
<thead>
<tr>
<th>Basic Failure Events</th>
<th>ID Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pressure equalizer valve failure</td>
<td>V1</td>
</tr>
<tr>
<td>2 Doors failure</td>
<td>D1</td>
</tr>
<tr>
<td>3 Seal failure</td>
<td>S1</td>
</tr>
<tr>
<td>4 Gearbox failure</td>
<td>G1</td>
</tr>
<tr>
<td>5 Minor pipe leakages</td>
<td>P1</td>
</tr>
<tr>
<td>6 Major pipe leakages</td>
<td>P2</td>
</tr>
<tr>
<td>7 Exhaust pipe failure</td>
<td>E1</td>
</tr>
<tr>
<td>8 Empty tank</td>
<td>T1</td>
</tr>
<tr>
<td>9 Tank failure</td>
<td>T2</td>
</tr>
</tbody>
</table>

What portfolios of risk management actions minimize the residual system risk for the different total cost of risk management actions?
Approach

- Convert the Fault Tree into a Bayesian network
- Formulate optimization problems for attaining safety targets (e.g., minimization of residual risk)
- Compute results with enumeration algorithms

Advantages

- Permits the modelling of multiples states
- Is a logical extension of AND/OR gates
Computational Results

- Minimum airlock failure probability for the optimal portfolio of actions at different budget levels
- Larger budget ⇒ more effective actions ⇒ lower residual risk

- These portfolios are globally optimal in terms of minimizing the residual system risk
- This can give significant improvements over the traditional approach of selecting actions that target risky components one at a time
Application of Human Reliability Analysis outside of PRA context

- The aim is to find
  - how HRA has been used outside of PRA and
  - what potential HRA has to widen its scope in the nuclear domain

- 7 organisations responded to a questionnaire
  - FKA, RAB, ÅF, LRC, Fortum, STUK, TVO

- Presently, most use of HRA is PRA related

- Possible HRA applications
  - development of instructions
  - operator training
  - control room design (validation)
  - occurred events analysis

- Several difficulties in using HRA in a non-PRA context
  - limited resources, limited project budgets
  - cross-organizational activity
  - lack of guidance

Elements of the HFE program’s review model (NUREG 0711 Rev. 3)