RASTEP

A novel tool for nuclear accident diagnosis and source term prediction based on PSA and Bayesian Belief Networks

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Outline

- Introduction
- Aim and scope of the RASTEP project
- Introduction to Bayesian Belief Networks (BBN)
- Development of a BBN for a nuclear power plant
- Overview of the RASTEP tool
- The FASTNET project
- Conclusion
Introduction

- Early source term prediction in connection with severe accidents is crucial
  - Utilities predict source terms, and provide predictions to authorities
  - Nuclear safety authorities has often an important role after a severe accident, involving both communication and technical aspects
  - Authorities needs in-house source term prediction capability

- Plant PSA:s in many countries are detailed, full scope and continuously updated (yearly)
  - Increasingly used for risk informed applications

- Possibility to
  - Make use of the detailed PSA information for source term prediction
  - Make use of a BBNs’ capabilities
Aim and scope of the RASTEP project

- The aim of the RASTEP project is to develop a tool for **RAPID SOURCE TERM PREDICTION** for practical use in severe accident situations, considering the specific needs of SSM’s emergency organization.

- While RASTEP has been tailored to the needs of the Swedish Radiation Safety Authority (SSM) the tool as such is well-suited for the needs of any emergency response organization or nuclear operator.

- The RASTEP project has been ongoing since 2009.
  - Including development of BWR and PWR models for Swedish NPPs.
  - Part of the scope in current phase is to verify and compare RASTEP outputs with similar results from SSM’s emergency preparedness organization.

- RASTEP is one of the tools that are evaluated in the EU project FASTNET (FAST Nuclear Emergency Tools, www.fastnet-h2020.eu)
  - 2015 – 2019
  - 20 partners from 18 countries.
Introduction to Bayesian belief networks (BBN)

- In a BBN, one node is used for each variable, which may be discrete, continuous or propositional (true/false)
- Conditional probability is the basic concept in the BBN
- Using Bayes theorem, one’s prior belief in the event (hypothesis) can be updated given the additional evidence (observation, finding)

\[
P(\text{State}|\text{Available information}) = \frac{P(\text{Available information}|\text{State}) \cdot P(\text{State})}{P(\text{Available information})}
\]
Example: BBN for emergency core cooling for PWR plant

Starting point – before any observations have been made

Conditional probability table (CPT) with statistical values

Lloyd's Register
Example: BBN for emergency core cooling for PWR plant

Starting point (as in previous slide)

Updated beliefs due to observations

Leads to update of belief in all nodes

Lloyd's Register
Developing a BBN for an NPP

- Mapping of plant characteristics
  - Definition of the physical source term volumes (STV) to be considered
  - Fission product (FP) transport and release routes
  - Mapping of severe accident management systems and actions
  - Key plant systems
  - Observable plant state parameters
  - Physical phenomena
- Development of the model
  - Model structure
  - Conditional Probability Tables (CPTs)
Mapping of plant characteristics

Release path diagram showing source term volume (STV) and fission product (FP) transport routes – BWR example
Development of the model

General model structure – BWR example

STARTING POINT
Initiating Event

Fuel Status
(degraded/molten core or not)

Availability of Core Cooling

Availability of Residual Heat Removal

Interfacing System Leak (IS-LOCA)

RELEASE from Reactor Building or Turbine Building

Status of Reactor Pressure Vessel

Status of SAM systems

Determination of Containment Failure Mode

RELEASE from Containment

Phenomena during Severe Accident Progression

PSA Level 1

PSA Level 2
Subnetworks – example – BBN of a Swedish BWR

Initiating event
Core cooling
RHR
Fuel status
RPV status
Containment status/phenomena
Reactor building status
Turbine building status
### Conditional Probability Tables – node categories

<table>
<thead>
<tr>
<th>Node category</th>
<th>Determination of CPTs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary condition node</td>
<td>Either 1 or 0, determined by user</td>
</tr>
<tr>
<td>Initiating event node</td>
<td>Derived from the <strong>initiating events (IE)</strong> in the <strong>PSA model</strong></td>
</tr>
<tr>
<td>System or function performance node</td>
<td>Derived from <strong>basic events or fault tree analysis cases in the PSA model</strong></td>
</tr>
<tr>
<td>Outcome determining node / source term node</td>
<td>Complex relationships, may rely on a mixture of engineering judgement, general considerations and calculations with the PSA, e.g. phenomena probabilities.</td>
</tr>
<tr>
<td>Measurement node</td>
<td>Consider both loss of detection and spurious detection. Prior assumptions regarding these failure modes are based on measurement component <strong>unavailability data</strong>.</td>
</tr>
</tbody>
</table>
PSA data – CPT modelling – BWR example

Prior probabilities are modelled using PSA data for:

- Initiating events
- Systems
- System function, requirements
- Manual actions
- Phenomena

Lloyd's Register
Graphical user interface

Question panel
- Visualization of the prediction for status of the initiating events, fuel and reactor vessel.
- Questions with possible answers to choose from.
- Opportunity to enter comments for specific issues / nodes.

List of observable nodes/questions
- Numbered questions linked to the relevant node in the BBN.
- Possibility to jump between questions.
- Detailed description for each node.

Source term prediction
- List of available source terms with related probabilities.
- The selected source term is shown in the graphs below.

Activity per phase
- Visualization of activity for individual nuclide groups per phase (histograms).
- Possibility to view the distribution of nuclides per phase with pie charts.

Releases over time
- Diagram showing emission for individual nuclide groups and total emissions (activity) over time.
- Possibility to show fractions of core inventory.
Source term prediction

- While responding to questions the source term prediction updates.

- The most probable sequence/source term is shown with a given probability on top of the list.

- Three possible locations for release (BWR model example):
  - Containment
  - Reactor building
  - Turbine building
Source term visualization per phase

- Histograms show source term per phase

- Pie-chart graphs show:
  - Release distribution per nuclide group per phase
  - Activities per nuclide group per phase
Source term visualization

- Activity release rates as histogram (TBq/h).
- Interpolation between points for time phases providing a rough estimation of cumulative released activity (TBq).
- Six nuclides that can be chosen separately.
- Fractions of core inventory in match with MAAP/MELCOR results.
RASTEP Case Report

Lloyd’s Register
The FASTNET project

Objectives

- Set-up severe accident scenarios databases
- Qualify a common response methodology that integrates tools and methods to:
  - Evaluate the source term
  - Ensure diagnosis and prognosis of accident progression
  - Make connection between FASTNET tools and other systems that use source term definition for further assessments
  - Propose communication to the public of emergency management approaches, measures and resources in Europe

Work packages

- WP1 – Scenarios database
- WP2 – Emergency preparedness
  (incl. evaluation of BBN techniques)
- WP3 – Emergency response
  (incl. BBN approaches)
- WP4 – Emergency exercises
- WP5 – Dissemination
  (knowledge sharing and training)
- WP6 – Project management

www.fastnet-h2020.eu
Conclusions

• RASTEP provides emergency preparedness organisations with an independent view of an accident progression and possible off-site consequences
• RASTEP makes it possible for utilities to quickly take relevant accident mitigating actions following a nuclear power plant accident
• RASTEP provides authorities with information following a nuclear power plant accident for prioritisation of actions and/or giving recommendations to emergency response organisations
Thank you

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