Use of PSA for SMRs
PSAM 16

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Lloyd's Register

RISK SPECTRUM

Overview

- Current focus in development of PSA tools
- Challenges with SMRs
- Focus on a few issues
- Conclusion

PSA methods development

Focus over the past years

- Manage larger and more complex models
- Calculation efficiency
- Calculation accuracy
- Including dynamic features

SMR challenges for PSA

A list of the most commonly discussed topics

- **Risk metrics and safe state** (especially for non-LWR SMRs)
- **Reliability data** estimation for components
- **Passive systems** reliability modelling
- **Digital I&C** systems reliability
- **Human reliability** (dependencies among multi-modules, long time windows)
- The use of traditional **mission times might be not applicable** (e.g. 24h)
- **Multi-module** interactions (positive and negative from risk point of view)

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Passive systems reliability and dynamic approches

- Passive systems are challenging to represent
  - Characterized by uncertainties
  - Lack of data – potentially insufficient understanding of phenomenon
  - Expected thermohydraulic simulations
- Are dynamic PSA tools the answer?
  - Can a SMR be fully represented in simulation tools?
  - Dependent on the design of the SMR
- Impossible to solve such models with the resolution used in PSA?
  - If the SMR contains similar systems like standard nuclear, with additional passive systems – this will likely NOT be possible to simulate using dynamic approaches

Passive systems reliability and dynamic approches

- Does this mean that dynamic approaches should not be considered?
  - Absolutely not
- The community should take the opportunity to embrace dynamic approaches as a complement
- Identification of relevant sequences and conditions that can be considered in the PSA model
  - Example “Treatment of Phenomenological Uncertainties in Level 2 PSA for Nordic BWR Using Risk Oriented Accident Analysis Methodology”
- Passive system reliability – will surely be needed to improve the current estimates

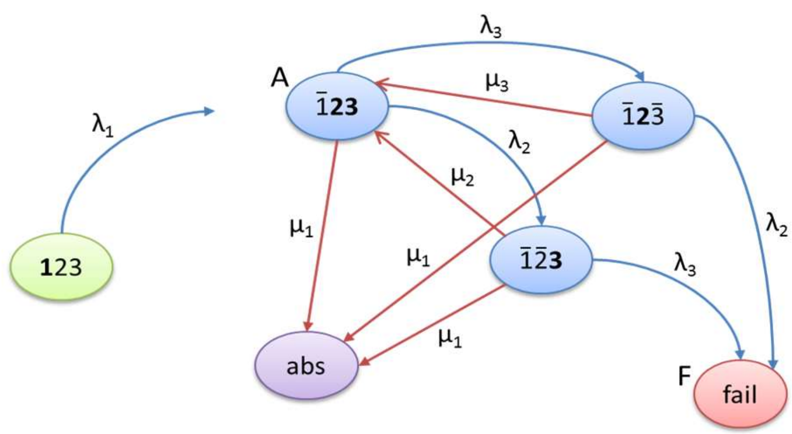
The use of traditional mission times might be not applicable

- Longer mission times should most likely be considered (days, weeks?)
  - At long mission times, the assumption to not consider repair is highly questionable
- Possible approaches tested in “Prosafe” project
  - Graded treatment of repair (“per cutset”)
  - RiskSpectrum I&AB (repair and long calculation times)
  - Simulation based approaches (“Dynamic”)

The use of traditional mission times might be not applicable

I&AB approach, implemented in RiskSpectrum

- Offers an integrated solution to model the dynamic behavior of failure and repair processes
- It is a simplification of a full Markov-chain
  - When the initiating event is repaired, the sequence terminates.
  - All stand-by objects are started at time zero
- The approach scales to large PSA



Multi-module interaction

- Current use is very limited
  - Most countries do not require multi unit risk
  - Different types of reactors, or different age
- For SMRs, will this still hold? Likely not!
- How can multi-unit risk be addressed in a reasonable way?
  - SITRON project (NKS-419)
  - Studied existing reactors, but should be applicable also to SMRs

Multi-module interaction

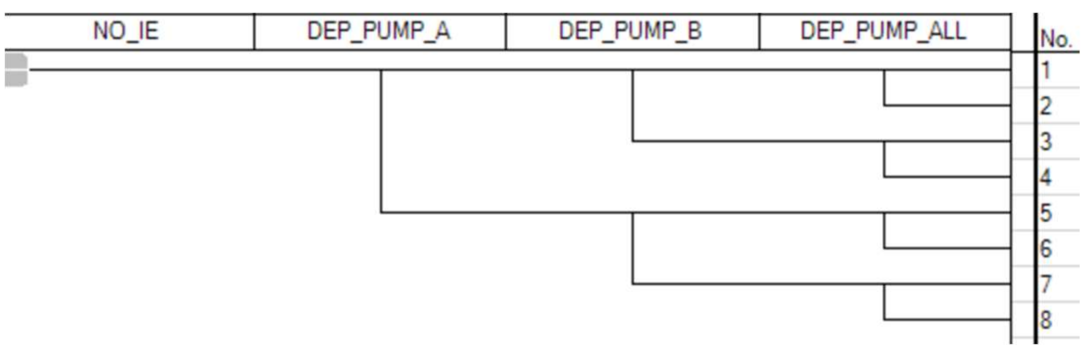
- The dependencies that were considered most relevant to study between units were:
  - Shared structures, systems and components (SSCs)
  - Identical components (CCF)
  - Human and organizational dependencies
- Is it possible to use the models of the individual plants to calculate the multi-unit risk?
  - Conclusion was yes and tested in pilots

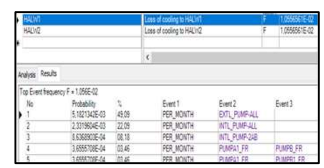
Multi-module interaction

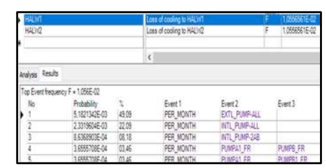
A possible solution under development with RiskSpectrum
Multi-unit event combinations approach

- $MUCDF_{IE} = F_{IE} \times \sum_{i=1}^{n} \left(\prod_{j=1}^{M_i} P_{i,IE,j} \right) \times p(CD_{unit1}|IEi) \times p(CD_{unit2}|IEi)$

- Example:
  - Assume two exactly same plants with two shared pumps
  - This can be thought of as an event tree – and then MCS lists for the units to consider at the end of each sequence

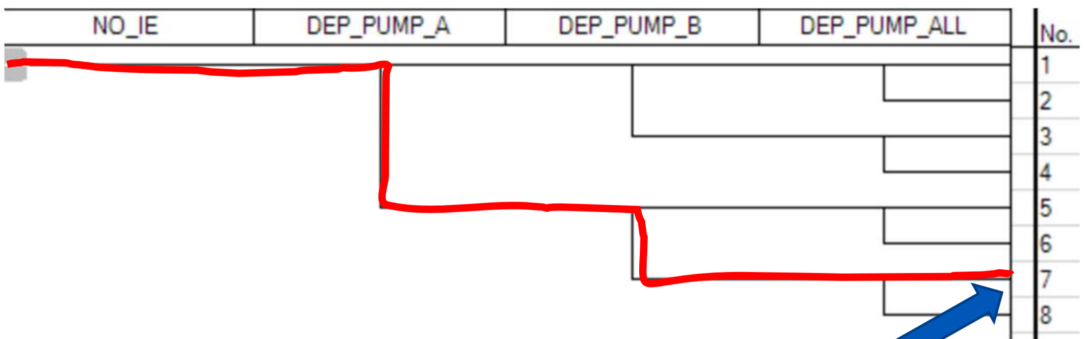






Multi-module interaction

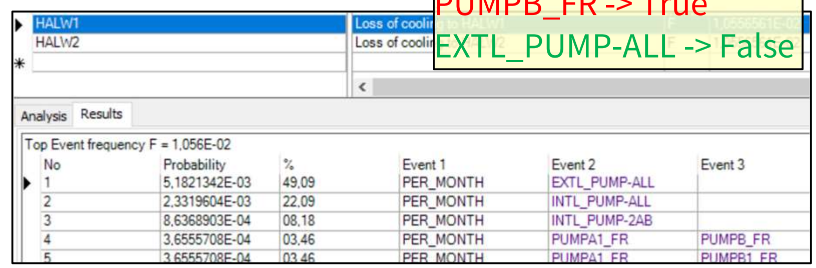
Example of RiskSpectrum implementation project



F(Seq7) x **Q(Unit 1)** x **Q(Unit 2)**

Unit 1

PUMPA_FR -> True
PUMPB_FR -> True
EXTL_PUMP-ALL -> False

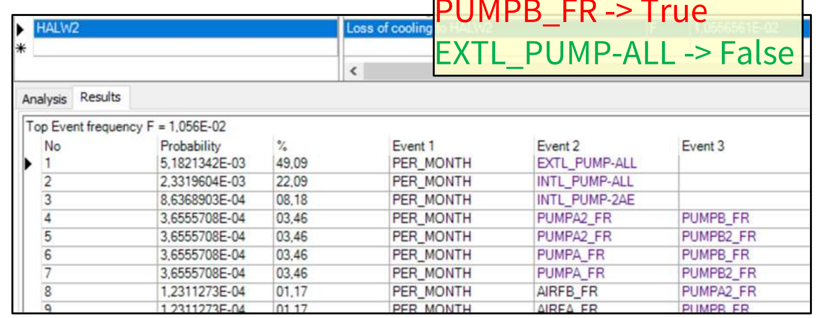


Top Event frequency F = 1,056E-02

No	Probability	%	Event 1	Event 2	Event 3
1	5,1821342E-03	49,09	PER_MONTH	EXTL_PUMP-ALL	
2	2,3319604E-03	22,09	PER_MONTH	INTL_PUMP-ALL	
3	8,6368903E-04	08,18	PER_MONTH	INTL_PUMP-2AB	
4	3,6555708E-04	03,46	PER_MONTH	PUMPA1_FR	PUMPB_FR
5	3,6555708E-04	03,46	PER_MONTH	PUMPA1_FR	PUMPB1_FR

Unit 2

PUMPA_FR -> True
PUMPB_FR -> True
EXTL_PUMP-ALL -> False



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4	3,6555708E-04	03,46	PER_MONTH	PUMPA2_FR	PUMPB_FR
5	3,6555708E-04	03,46	PER_MONTH	PUMPA2_FR	PUMPB2_FR
6	3,6555708E-04	03,46	PER_MONTH	PUMPA_FR	PUMPB_FR
7	3,6555708E-04	03,46	PER_MONTH	PUMPA_FR	PUMPB2_FR
8	1,2311273E-04	01,17	PER_MONTH	AIRFB_FR	PUMPA2_FR
9	1,2311273E-04	01,17	PER_MONTH	AIRFA_FR	PUMPB_FR

Conclusions

- Main issues for PSA for SMRs seem to be
  - Passive system reliability, safe state and multi-unit interaction
- Current PSA concepts and tools are fit for purpose for demonstrating the safety case
- Passive system reliability will most likely need additional tools
- Use of dynamic approaches for identifying sequences
- Multi unit risk will likely not be possible to disregard from

Thank you

Please contact:

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