Measuring Risk Importance in a Dynamic PRA Framework

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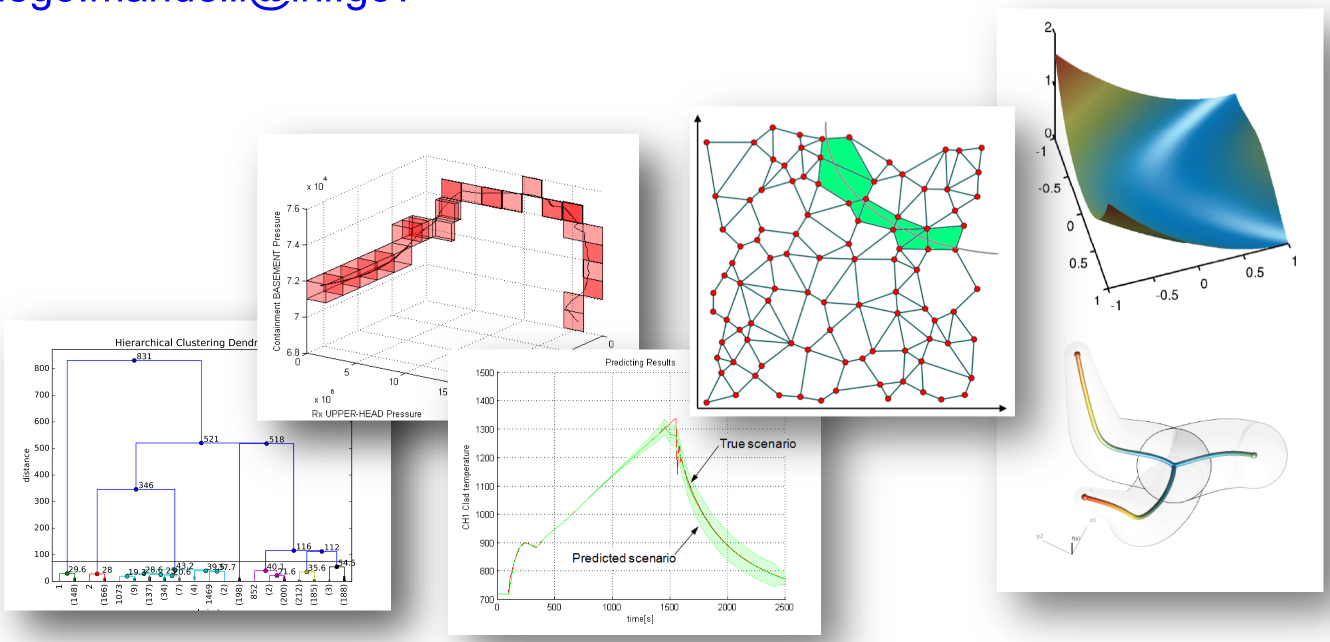


IRUG Meeting– Idaho Falls, May 2018

Work Summary

- Risk Importance Measures (RIMs) in PRA
  - Fusel-Vessely, Risk Achievement Worth
  - Applied to Minimal Cut Sets
- Extension of classical RIMs for Dynamic PRA data
  - Large number of simulated accident scenarios
- Application to PWR LB-LOCA
  - Classical vs. Dynamic PRA

Classic RIMs from ET/FT Data

- All classic RIMs are calculated by determining:
  - R_0 : nominal Core Damage Probability (CDP)
  - R_i^- : CDP for basic event *i* assumed to be perfectly reliable
  - R_i^+ : CDP for basic event *i* assumed failed

- RIMs:
  - Risk Achievement Worth (RAW): $RAW_i = \frac{R_i^+}{R_0}$
  - Risk Reduction Worth (RRW): $RRW_i = \frac{R_0}{R_i^-}$
  - Birnbaum (B): $B_i = R_i^+ - R_i^-$
  - Fusel-Vessely (FV): $FV_i = \frac{R_0 - R_i^-}{R_0}$

Classic RIMs from Simulation-Based Data

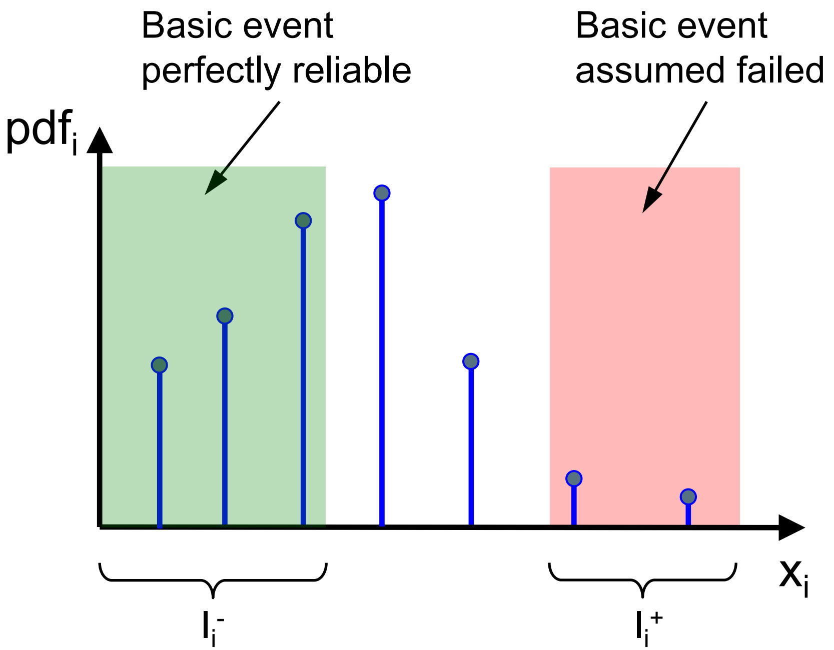
- Dynamic PRA:
  - Large number of simulated accident scenarios
  - Timing/sequencing of events is dictated by:
    - System control logic
    - Sampled parameters
  - Sampled parameters are analogous of Basic Events

- Possible approaches:
  1. Perform an analysis for R_o and for each basic event *i* determine R_i^- and R_i^+
     - For *N* basic events, 2 *N* + 1 analyses are required
     - Tremendously computationally expensive

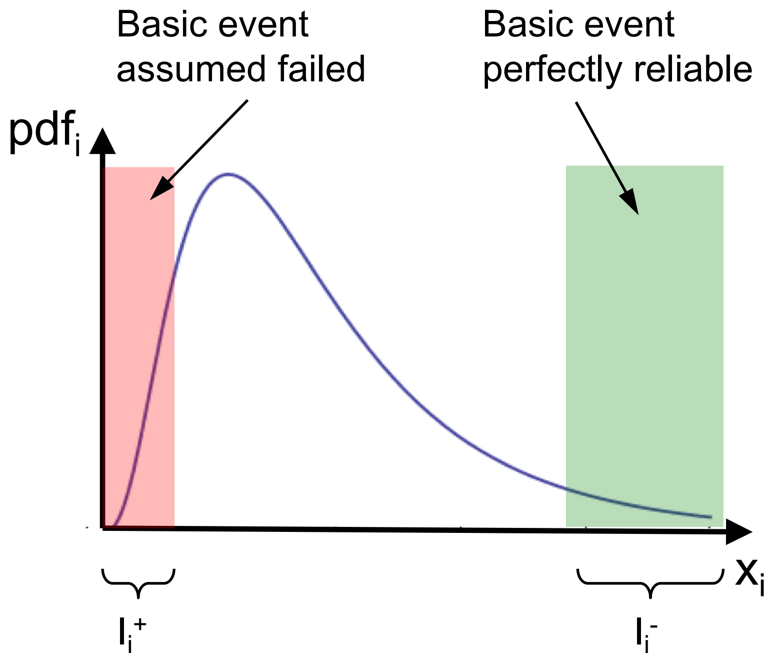
  2. Determine R_i^- and R_i^+ from the simulations generated to calculate R_o

Classic RIMs from Simulation-Based Data

- How can R_0 R_i^+ R_i^- be determined from simulation-based data sets?
- Define for each basic event *i* (sampled parameter):
  - I_i^- region where basic event *i* is assumed to be perfectly reliable
  - I_i^+ region where basic event *i* is assumed failed



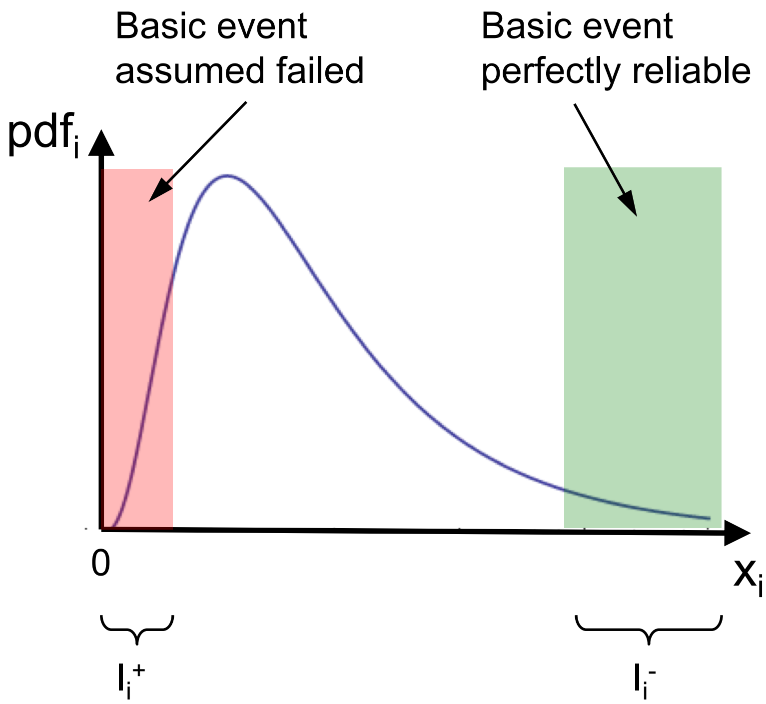
e.g., Grid recovery time



e.g., EDG failure time

Classic RIMs from Simulation-Based Data

- Determine R_0 R_i^+ R_i^- for each basic event *i* (Monte-Carlo case):
  - $R_0 = \dfrac{N_{CD}}{N}$
  - $R_i^+ = \dfrac{N_{CD, x_i \in I_i^+}}{N_{x_i \in I_i^+}}$
  - $R_i^- = \dfrac{N_{CD, x_i \in I_i^-}}{N_{x_i \in I_i^-}}$



- Note: special attention needs to be given to the sampling strategy

Classic RIMs from Simulation-Based Data

- Testing:
  - Several analytical tests have been developed for different configurations
    - Parallel/series
    - Stand-by
    - K out of N
  - Initial comparison with SAPHIRE on more advanced cases has been started
  - Perfect agreement within statistical error

Idaho National Laboratory

Application

- Test case:
  - 3-loop PWR system
  - Large break LOCA (LB-LOCA)

- Systems considered:
  - Accumulators (ACCs)
  - Low Pressure Injection System (LPI)
  - Low Pressure Recirculation (LPR)

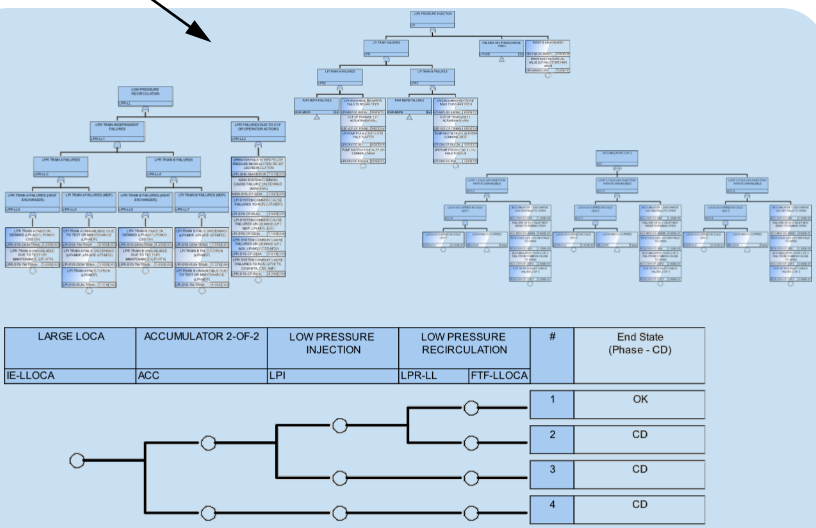
- Scope of the analysis:
  - Validation step
  - Measure differences between Classical and Dynamic PRA analyses

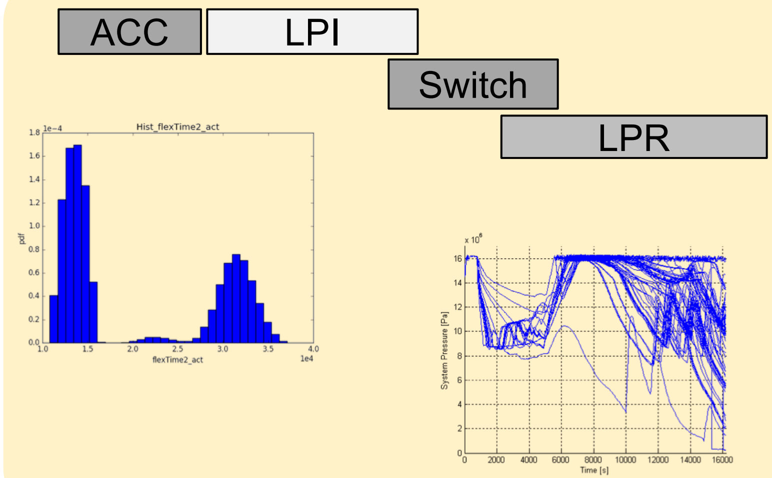
Application

SAPHIRE

Set of basic events and associated probabilities

RAVEN coupled with RELAP5-3D





Comparison Metrics:

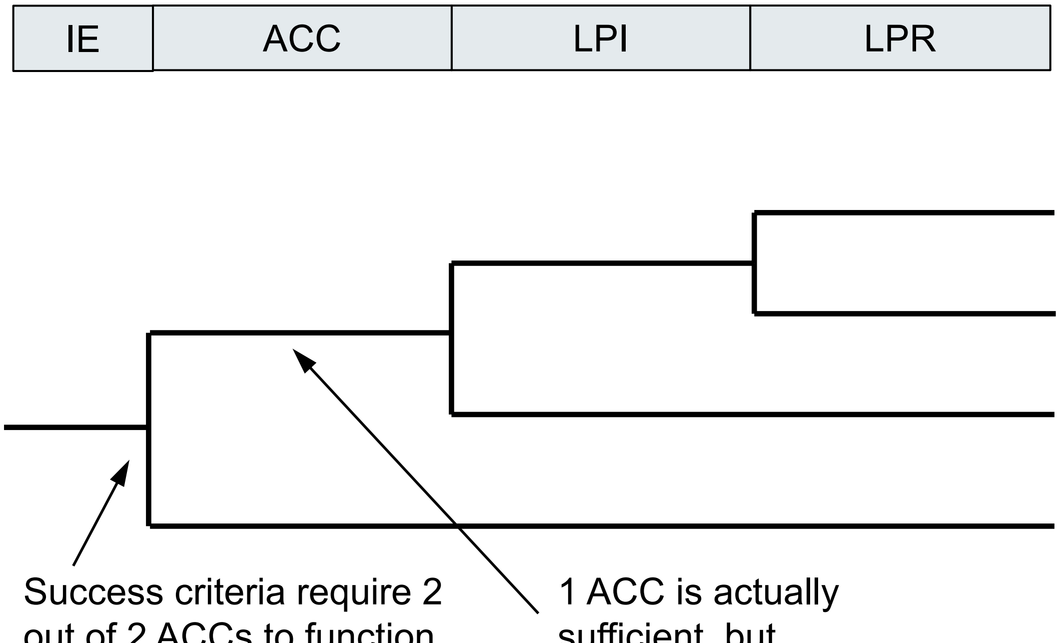
- CD probability
- Risk Importance of SSCs
- Event sequence probability

Associate each simulated scenario to a specific ET branch

Results

- CD probability:
  - Dynamic PRA (RAVEN-RELAP5): 8.24 E-3
  - Classical PRA (SAPHIRE): 8.13 E-3

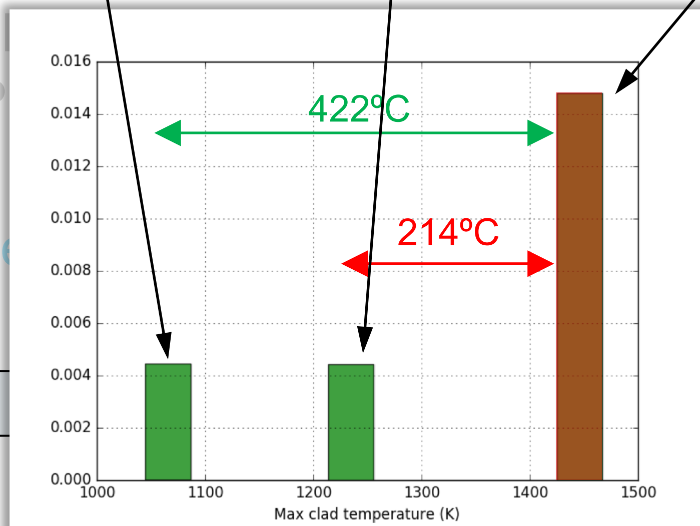
- Event sequence probabilities:



ID	Out	Branch Probability: SAPHIRE	Branch Probability: RAVEN
1	OK	0.99187	0.99176
2	CD	7.27 E-3	7.365 E-3
3	CD	8.12 E-4	8.744 E-4
4	CD	4.80 E-5	5.76 E-10

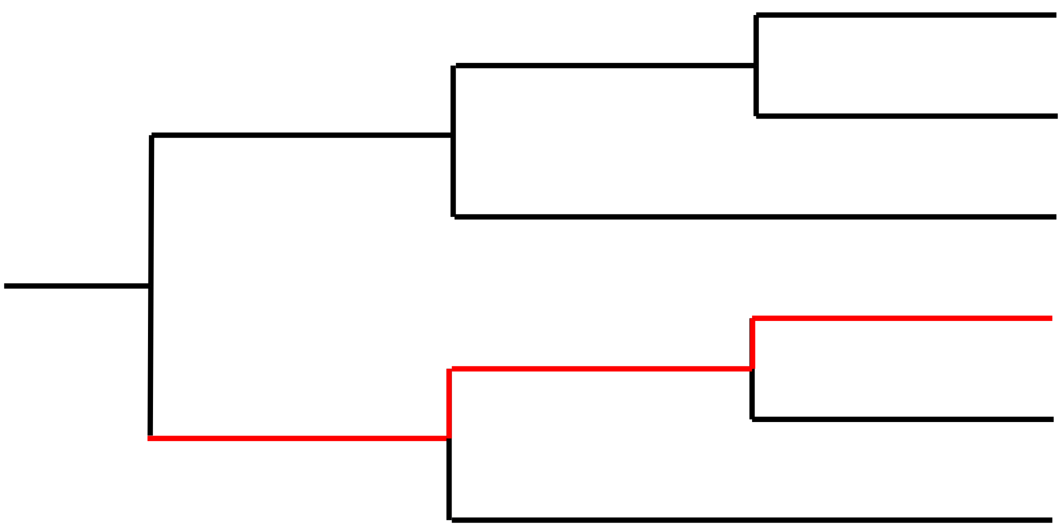
Results

- CD probability
  - Dynamic P
  - Classical P
- Event sequence



IE	ACC	D	#	Out	Branch Probability SAPHIRE	Branch Probability RAVEN
			1	OK	0.99187	0.99176
			2	CD	7.27 E-3	7.365 E-3
			3	CD	8.12 E-4	8.744 E-4
			4	CD	4.80 E-5	5.76 E-10

Results



IE	ACC	LPI	LPR	ID	Out	Branch Probability: SAPHIRE	Branch Probability: RAVEN
				1	OK	0.99187	0.99176
				2	CD	7.27 E-3	7.365 E-3
				3	CD	8.12 E-4	8.744 E-4
				4	OK		5.712 E-10
				5	CD	CD 4.80 E-5	4.242 E-12
				6	CD		5.036 E-13

Results

- RIMs:
  - Drastic decrease for basic events associated to ACC
  - RIM analysis considered a small subset of the simulated data

- What about the rest of the data?
  - Measure safety margin (SM):

$$SM = 2200 - PCT$$

  - Characterize the pdf of SM
    - mean, std. dev.

Summary

- Classical RIMs can be generated from simulation based data

- Rationale: classical and dynamic PRA can coexist
  - Reduce ET/FT conservatisms
  - Employs simulation-based success criteria
  - Measure safety margins

- Hybrid PRA:
  - Start from classical PRA model
  - Validate outcome and probability of all ET branches
    - measure safety margins
  - Perform UQ on simulation models for borderline ET branches
  - Introduce time-dependent elements (e.g. recovery) for specific event sequences