Linking Classical PRA Models to a Dynamic PRA

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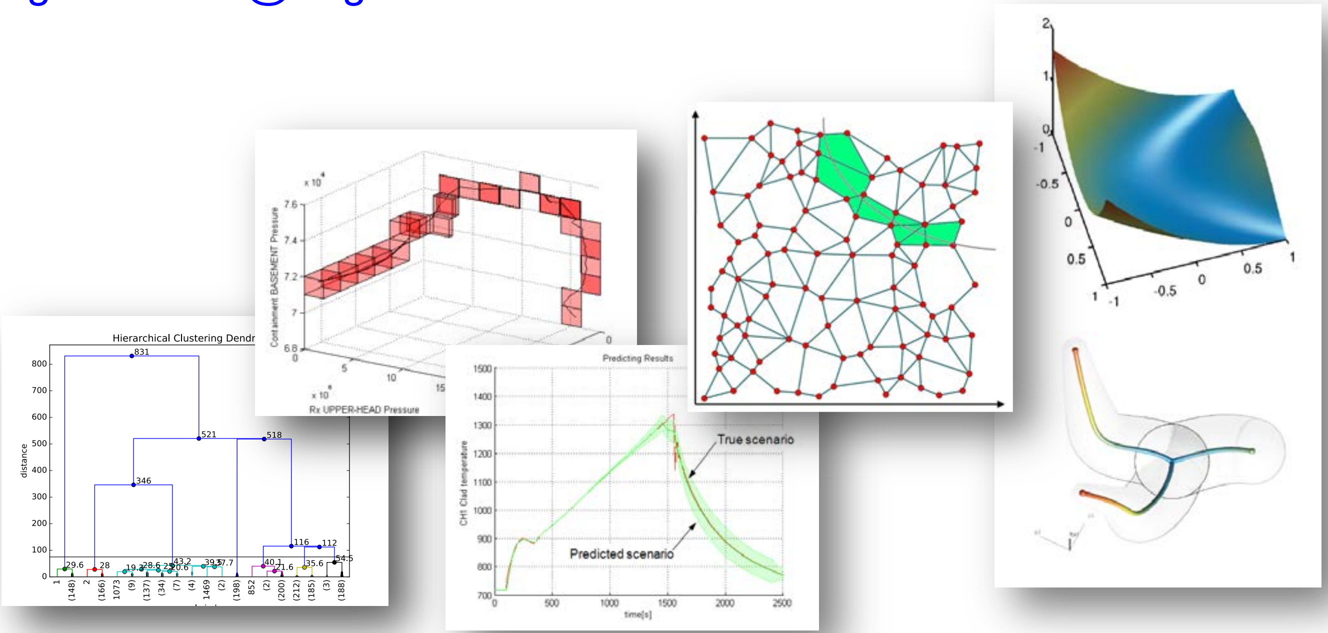

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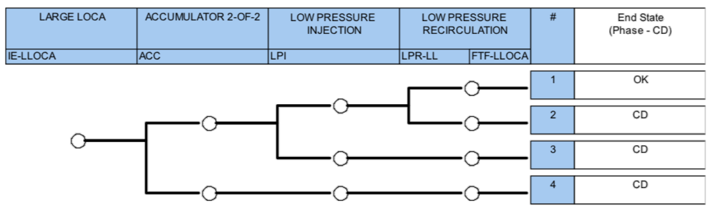
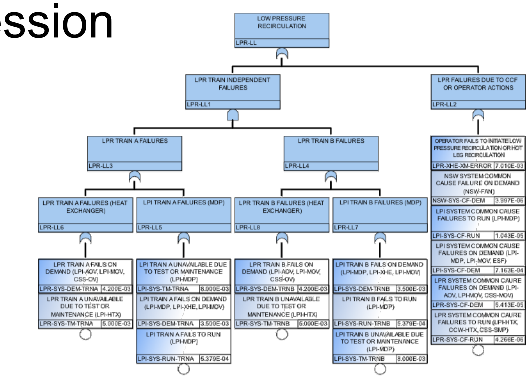
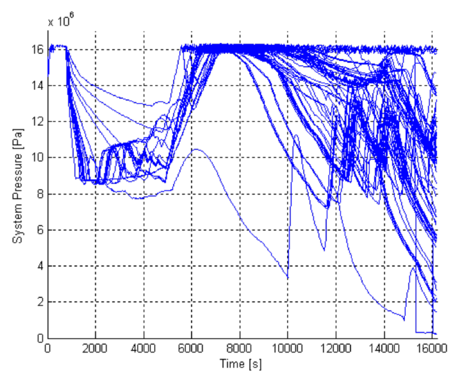
Classical and Dynamic PRA

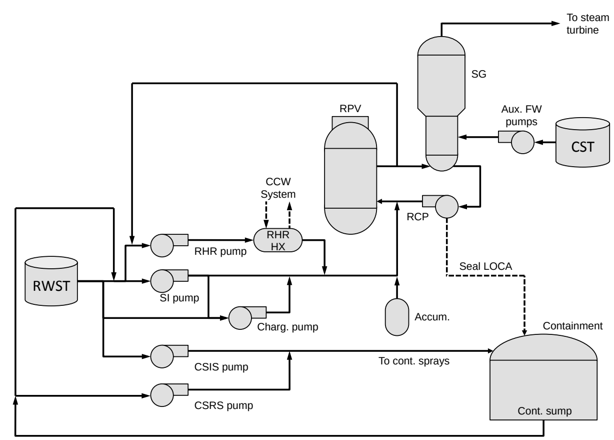
- Classical PRA: based on static Boolean structures
  - Event-Trees (ET): inductively model accident progression
  - Fault-Trees (FT): deductively model system failure





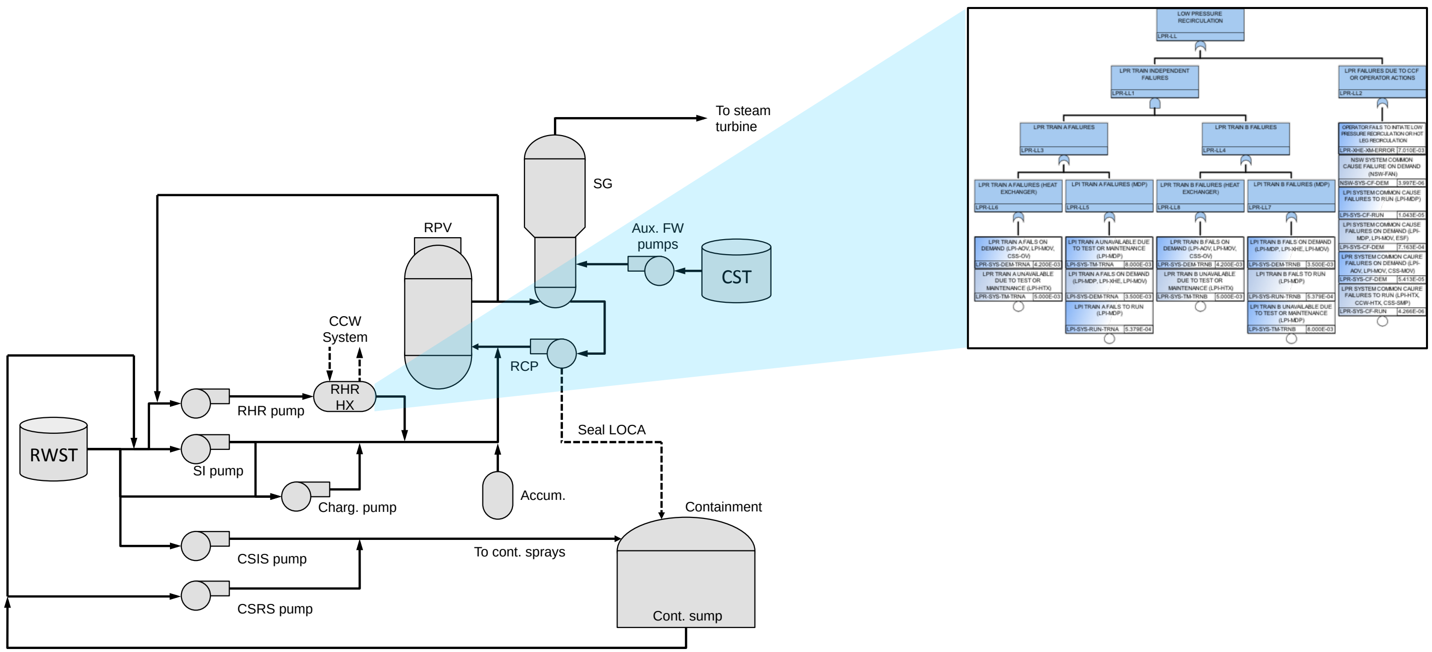
- Dynamic PRA: simulation-based methods that couple:
  - System simulator codes (e.g. RELAP5-3D)
  - Stochastic tools (e.g., RAVEN)





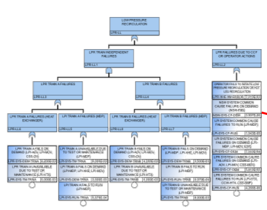
Classical and Dynamic PRA

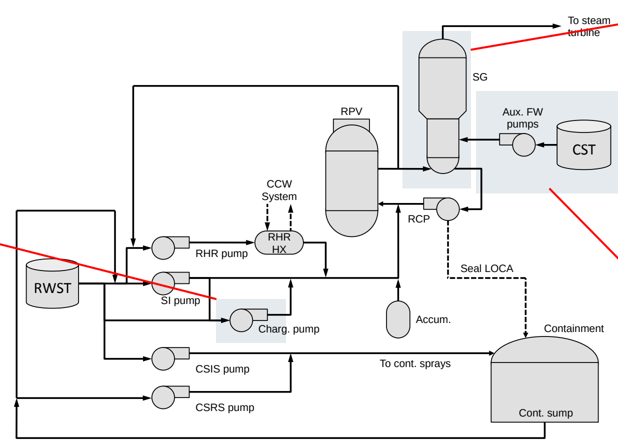
- Issues related to the Dynamic PRA analysis:
  - Computationally expensive
  - Some components of the system might not require a simulation model
  - Implementation of control logic systems in a system simulator might be challenging

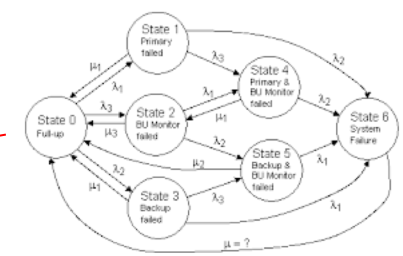


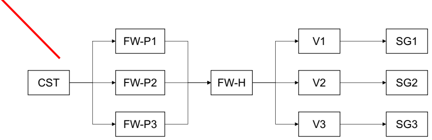
Objectives of the Integration

- Integration of Classical models into a Dynamic PRA
  - Rationale: some systems/components might not require a simulation model
    - Could be modeled by employing a Classical PRA model (e.g., a FT)
  - Objective: integrate Classical PRA models into a Dynamic PRA (“Hybrid” PRA)
    - ETs
    - FTs
    - Reliability Block Diagrams (RBDs)
    - Markov models









Integration

- In Dynamic PRA time is explicitly considered
- Most Classical PRA models are based on Boolean logic structures
- Each Dynamic PRA model is characterized by a precise set of input and output variables

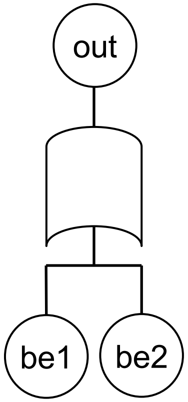
- Approach:
  1. Define input and output variables for each Classical PRA model

Model	Input Variables	Output Variables
ET	Branching conditions	Sequence, Outcome
FT	Basic Events	Top Event
Markov model	Initial state, End time	Final state
RBD	Block statuses	System status

  2. Extend Classical PRA models to deal with time dependent data; e.g., pump failure time instead of pump failure
  3. Link models (e.g., FT and RBD with RELAP5) together

Extending FT to Time Domain

- Challenge: Basic Events of a FT can be different in nature (Boolean or time value)
- Gate values are consequently different in nature depending on the type of value of the Basic Event
- Example: FT AND gate

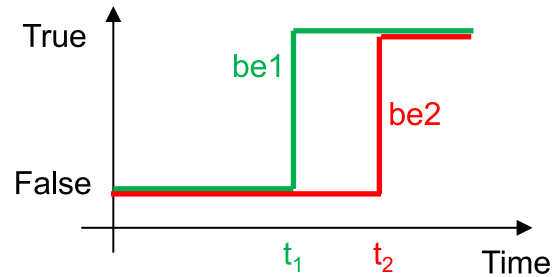


Boolean

be_1	be_2	out
False	False	False
False	True	False
True	False	False
True	True	True

Time dep.

be_1	be_2	out
t_1	t_2	$\max(t_1, t_2)$



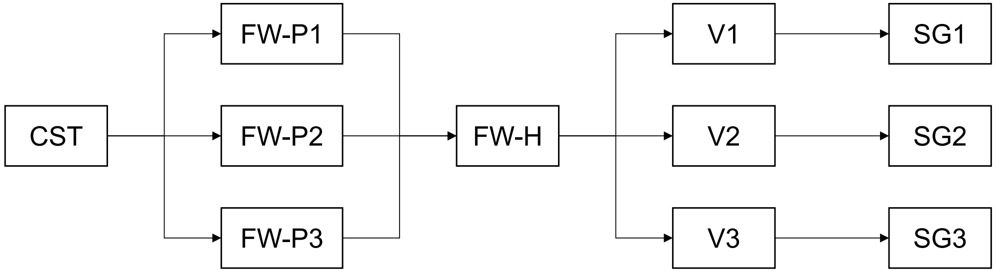
Boolean and time dep.

be_1	be_2	out
False	t_2	False
True	t_2	t_2

- Solution: An algorithm has been developed in RAVEN which:
  - Given a generic FT structure
  - Computes the outcome of the FT Top Event for a generic set of values of the Basic Events

Extending RBD and Markov Models to Time Domain

- RBD: a similar algorithm has been developed for RBD

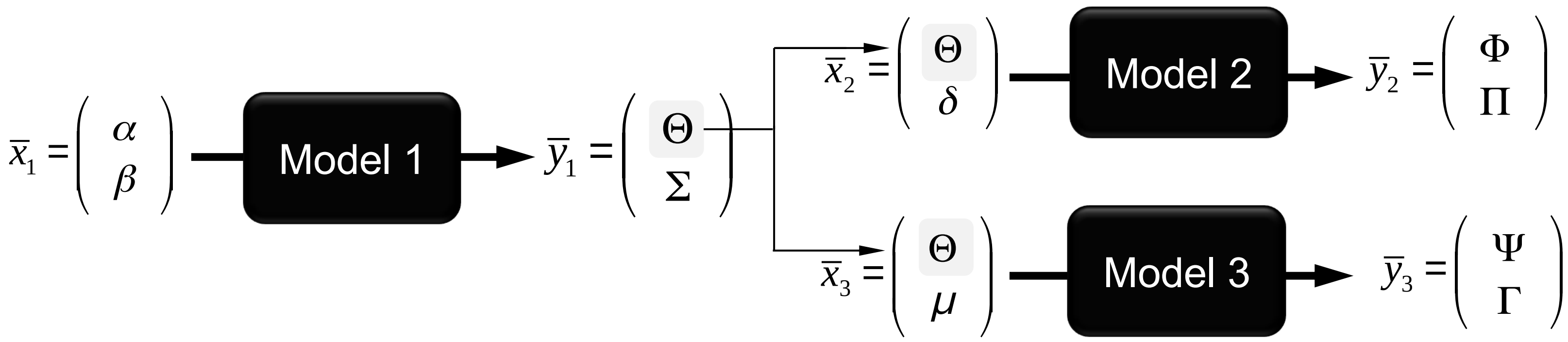


SG1: `Top Event = (FW-P1 and FW-P2 and FW-P3) or FW-H or V1`

- Markov Models:
  - Input variables: Initial State, Transition Matrix, End Time
  - Output variable: State at End Time
  - Procedure: Perform transitions among states until End Time is reached

Linking Models: RAVEN Ensemble Model

- Multiple “models” can be assembled together and treated as a single one
- Models can be completely heterogeneous:
  - Codes
  - External models
  - Reduced Order Models
- RAVEN acts as a hub for the information exchange
- Information passing between “models” could be:
  - Point values
  - Time Series
- Example:



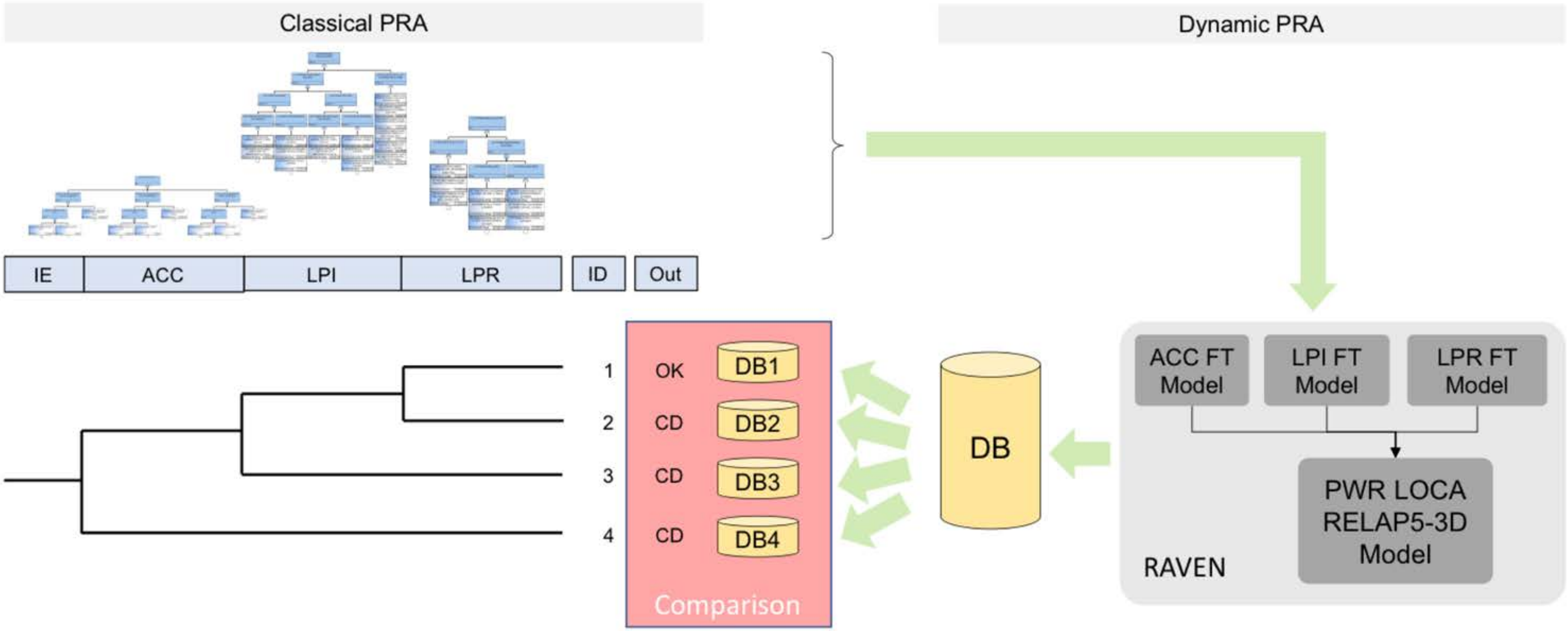
Application

- Test case:
  - 3-loop PWR system
  - Large break LOCA (LB-LOCA)
    - 6”, 8”, 10” and double-ended guillotine (2A)

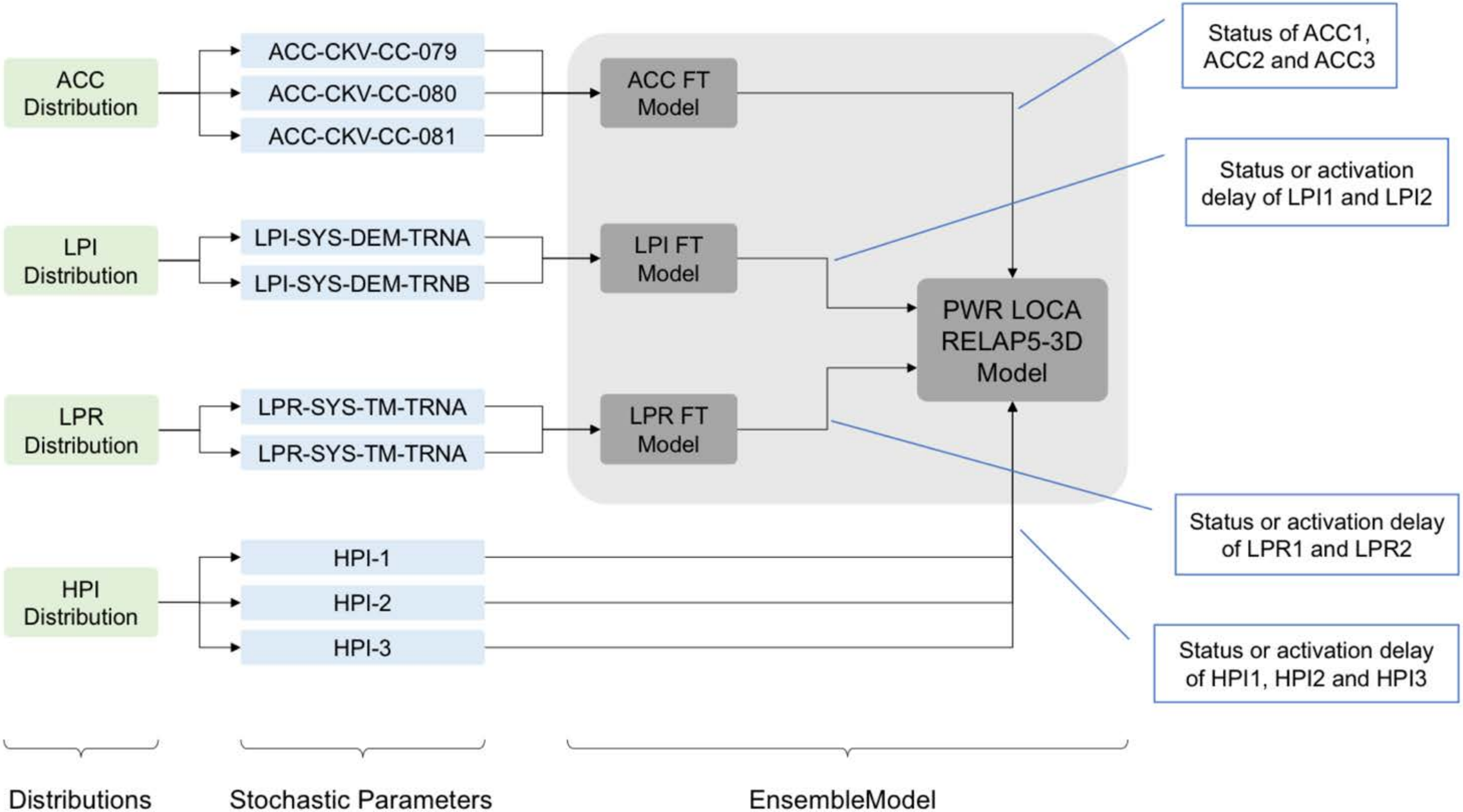
- Systems considered:
  - Accumulators (ACCs)
  - Low Pressure Injection System (LPI)
  - Low Pressure Recirculation (LPR)

- Scope of the analysis:
  - Show how FTs can be linked to RELAP5
  - Measure differences between Classical and Dynamic PRA

Classical And Dynamic PRA: Comparison Methodology

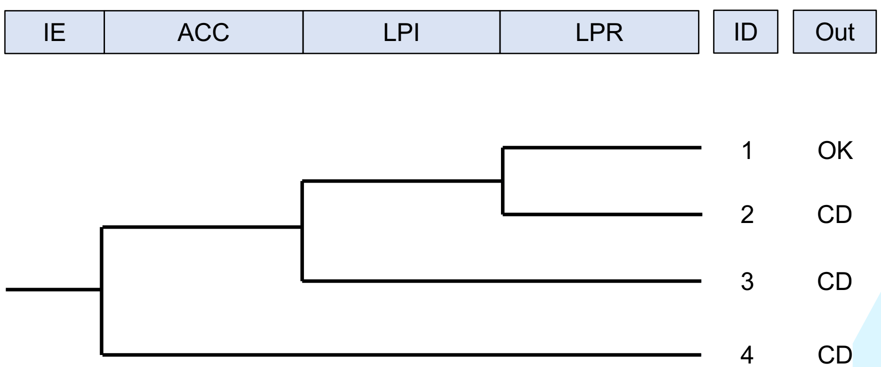


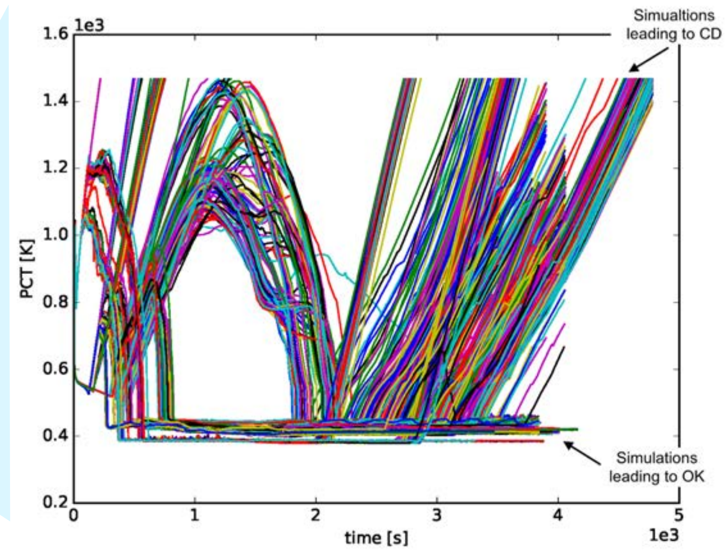
LB-LOCA Dynamic PRA



Results

- Classical and Dynamic PRA results agree for the first three branches
- Disagreement on Branch 4:

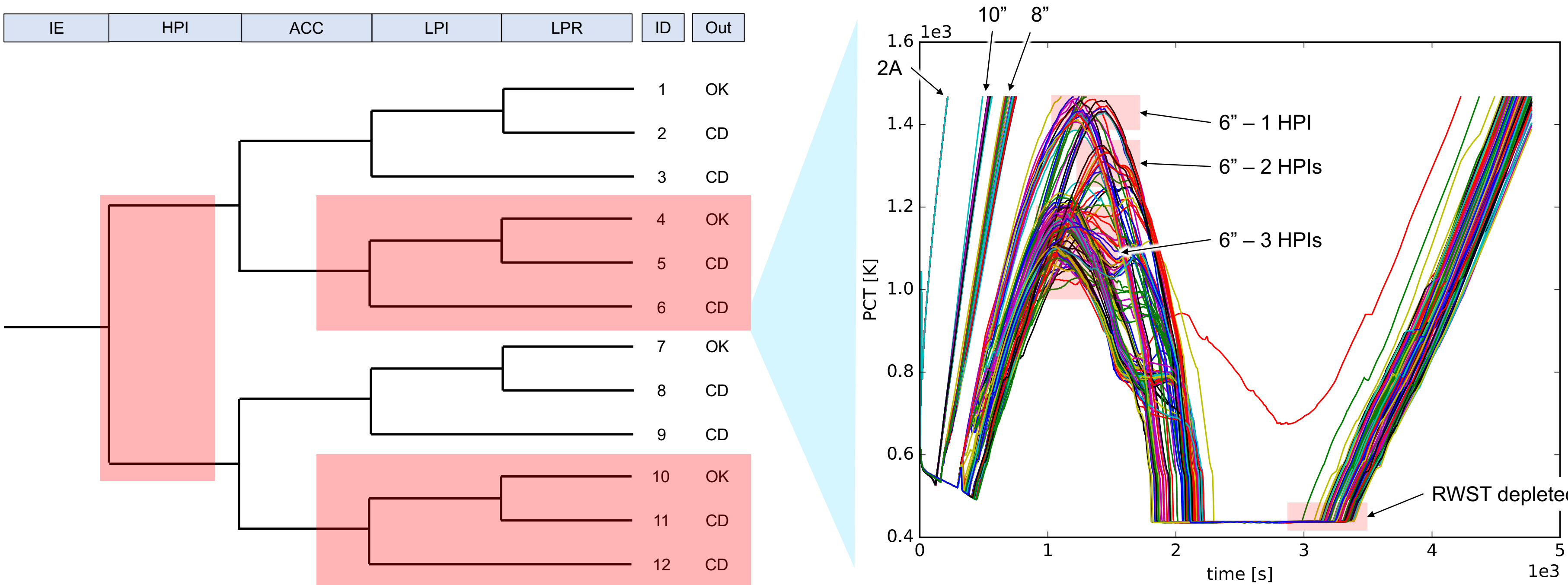




- ET needs to be re-structured
  - Added new ET branching condition: HPI
  - Expanded part of ET after failure of the ACC system

Re-structured ET

- Analysis focuses on OK branches: determining safety margins



Branch	6”	8”	10”	2A”
1	[620,750]	[620,790]	[615,620]	[1045,1050]
4	[750,970]	[770,860]	[710,780]	[1050,1260]
7	[620,630]	[620,650]	[615,620]	[1045,1050]
10	[910,970]	[820,890]	[730,820]	[1150,1270]

Conclusions

- We have shown how Classical PRA models can be linked to RELAP5-3D by employing RAVEN
  - Application areas: U.Q. and PRA

- PRA applications:
  - Validation of existing PRAs
  - Integration of simulation-based data into existing PRA