Development of a Station Blackout Benchmark Case Study for Dynamic Probabilistic Risk Assessment

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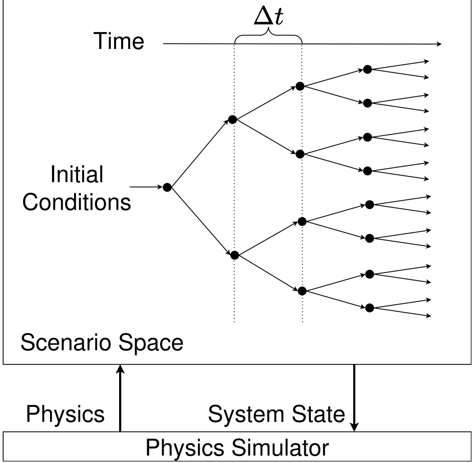
Dynamic Probabilistic Risk Assessment

- Dynamic PRA methods: Couple system physics with stochastic system models[1]
- Typically system physics are evaluated with simulations
- Dynamic PRA methods address some limitations in conventional PRA
  - Physics dependencies
  - Event timing/ordering
  - Human reliability



[1] *Nathan Siu (n.d.). Technical Opinion Paper, Draft for Comment ML19066A390. US Nuclear Regulatory Commission*

Motivation

Many existing case studies in dynamic PRA highlight different capabilities

- Focus on failure on demand
- Variable scope

Dynamic PRA is meant to handle physics dependence, context-driven human interactions, etc.

Objective

This work develops part of a proposed dynamic PRA benchmark case study

- Failure on demand
- Time distributed events
- Operator actions
- Physics dependent events

- Initiating event (Station Blackout)
- System model (4-Loop Pressurized Water Reactor)

Several events have been selected which correspond to the expected plant response to station blackout, categorized by its most specific category

Initiating Event

Station blackout is the condition where all AC power is lost at a nuclear power plant

In this proposed case study

- DC power is available, but may later be lost as the batteries deplete
- Onsite and offsite AC power are assumed lost at time zero
- Onsite and offsite AC power can be recovered (individually) later in an accident sequence
- Power loss is caused by severe weather conditions

Plant Response

Following the loss of power, emergency systems and plant operators must act appropriately to maintain cooling of the nuclear fuel

- Operation of the turbine-driven auxiliary feedwater pump
- Timely restoration of AC power and associated emergency core cooling systems

Operation of plant systems and performance of operators are subject to stochastic failures

- Failures may result in uncontrollable transient behavior
- System consequences occur if the fuel cladding temperature exceeds a given threshold

Failure On Demand

These events may occur whenever a component is demanded to respond

- Failure of automatic reactor trip
- Main steam isolation valve failure to automatically close
- Turbine driven auxiliary feedwater pump[2] failure to automatically start
- Pressurizer/Steam generator power operated/safety relief valve failure to open/close
- Emergency core cooling system failure to start

- 60 seconds after the initiating event, the turbine driven auxiliary feedwater pump may fail to start with probability 3.79×10^{-3}, but may be later recovered by operator action[3]

[2] *Discussed in detail later*

[3] *Zhegang Ma, Thomas E. Wierman, and Kellie J. Kvarfordt (Nov. 2021). Tech. rep. Idaho National Laboratory (INL), Idaho Falls, ID (United States).*

Time Distributed Events

These events occur with a probability computed from a probability distribution over time

- Recovery of offsite/onsite AC power
- Turbine driven auxiliary feedwater pump[4] failure to run
- Depletion of DC batteries

- DC battery depletion time t is given by $t \sim \text{triangular}(\text{min} = 2\text{hr}, \text{mode} = 6\text{hr}, \text{max} = 8\text{hr})$[5]

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[4] *Discussed in detail later*

[5] *J LaChance et al. (2012). Tech. rep. Sandia report, SAND, p. 2012.*

Operator Actions

Operator actions are modeled using a combination of the SPAR-H[6] and HCR[7] HRA methods

- Manual reactor trip following automatic trip failure
- Manual main steam isolation valve closure following automatic failure to close
- Manual activation of the turbine driven auxiliary feedwater pump[8] following automatic activation failure
- Manual start of the emergency core cooling system following failure to automatically start

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[6] *D. I. Gertman et al. (Aug. 2005). Tech. rep. NUREG/CR-6883, INL/EXT-05-00509. Idaho National Laboratory.*

[7] *Gareth W Parry et al. (1992). Tech. rep. TR-100259. Electric Power Research Institute.*

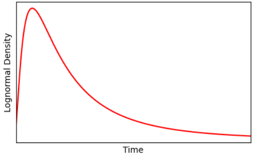
[8] *Discussed in detail later*

Operator Modeling

Operator Response

Diagnosis - HCR[9]

Action - SPAR-H[10]



- Physics dependent stress
- Other performance shaping factors constant

[9] *Gareth W Parry et al. (1992). Tech. rep. TR-100259. Electric Power Research Institute*

[10] *D. I. Gertman et al. (Aug. 2005). Tech. rep. NUREG/CR-6883, INL/EXT-05-00509. Idaho National Laboratory*

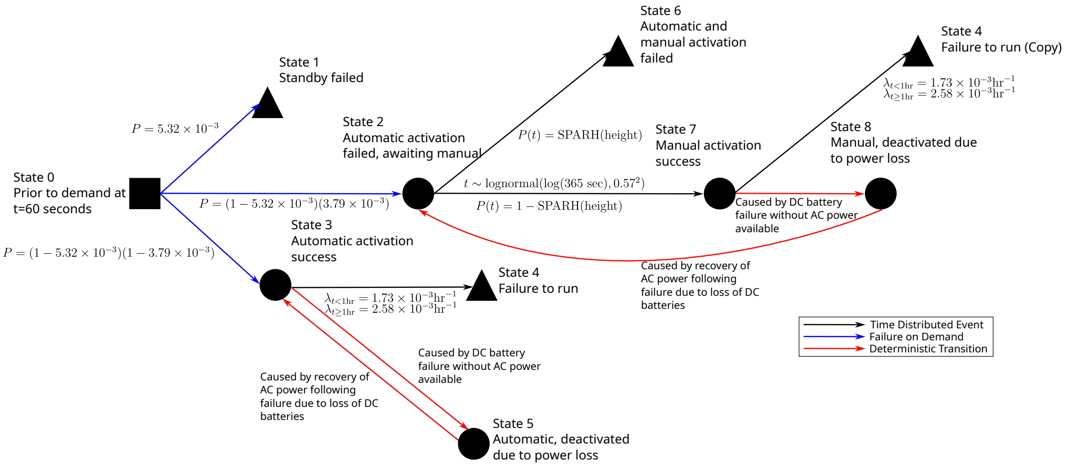
Physics Dependent Events

Physics dependent events have probabilities computed as a function of the system dynamics within each accident sequence

- Degradation of the reactor coolant pump seal
- Creep rupture of the pressurizer surge line
- Creep rupture of steam generator tube

- $R(t_f) = \int_0^{t_f} 10^{-p(t)/T(t)-20} dt$
- Probability calculated using lognormal distribution of R with parameters $\mu = 0$ and $\sigma = 0.4$

Example Component Model



Turbine driven auxiliary feedwater pump state evolution

Conclusions

This work describes a set of stochastic events to be included in a proposed benchmark case study for dynamic PRA

- Station blackout of a 4-loop pressurized water reactor
- Events include
  - Failure on demand
  - Time distributed events
  - Operator actions
  - Physics dependent events
- Some events are easy to incorporate into conventional PRA, others not

If adopted by the wider dynamic PRA community, the proposed case study will highlight the capabilities of different dynamic PRA methods

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Thank You for Your Attention

Questions?

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