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Using Operational Experience to Support Dynamic PRA Activities

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Outline

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- Objective
- Approach
- Events descriptions and Dynamic Interactions
- Conclusions
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Background

Over the years, Dynamic PRA (DPRA) has been advocated as a potentially useful supplement to commonly used event tree/fault tree methods.

There has been only limited formal investigation of dynamics observed during actual operating events that might be important to consider in a decision that would support the use of DPRA.

Objectives

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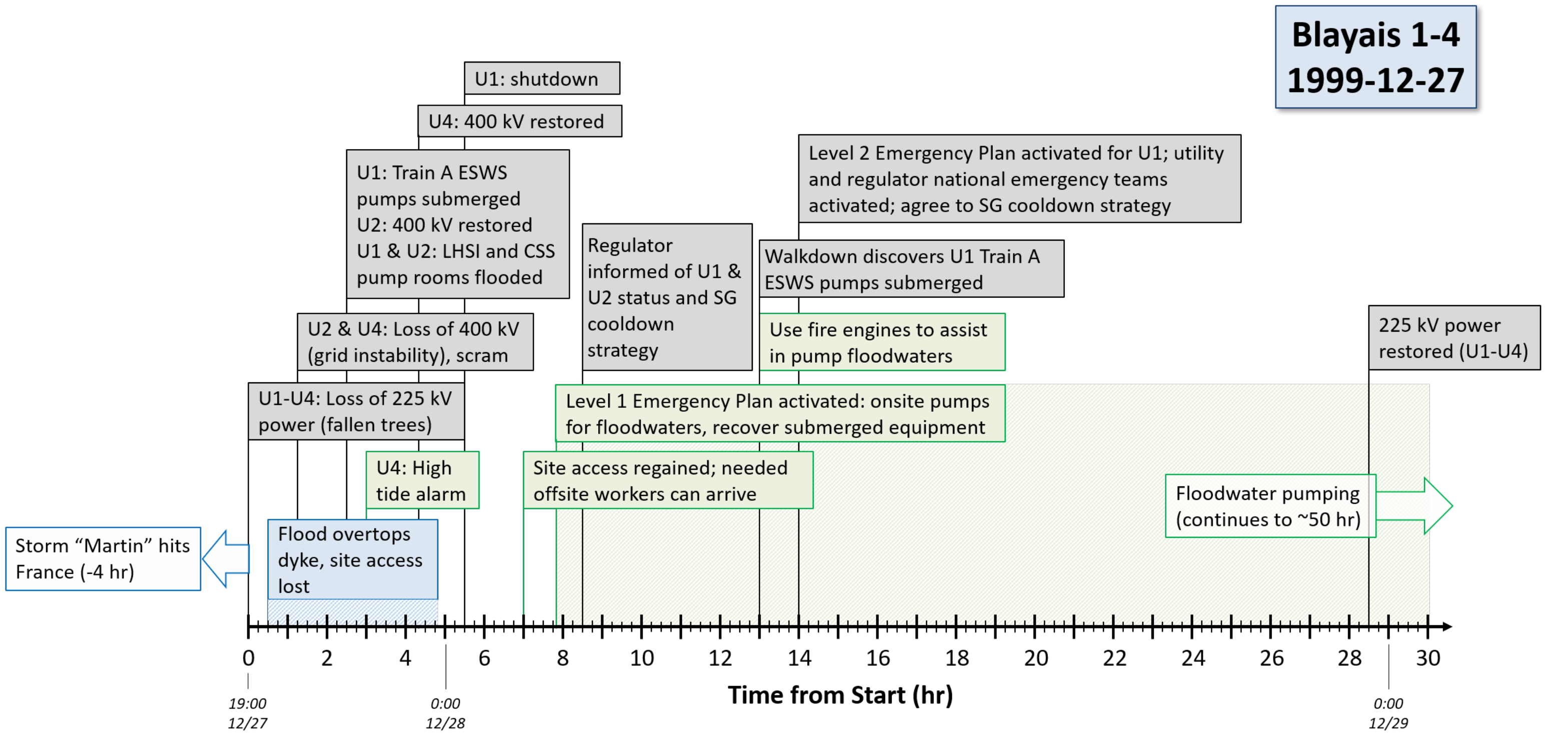
- The objective of this work was to describe the status and current results of a limited scope, exploratory, qualitative study that:
  - Reviews some past nuclear power plant reactor incidents for important dynamic behaviors during the incidents
  - Considers if and how a DPRA might improve on conventional PRA treatments of such features
    - To suggest classes of behaviors that should be considered when performing a DPRA.
- The study does not address heavily documented or highly complex nuclear power plant accidents (TMI, Chernobyl, Fukushima Daiichi)

Approach

- Reviewed individual event reports to identify selected dynamics.
- The review focused on the identification and characterization of the system elements and their interactions (e.g. external elements, local environment, operators)
- 5 events analyzed:
  - 1959 fuel melting accident at the Sodium Reactor Experiment
  - 1985 loss of main feed water at Davis Besse
  - 1989 turbine oil fire at Vandellos
  - 1999 flood incident at Blayais
  - 2020 loss of offsite power at Duane Arnold



Timeline for Blayais Flooding Event

Event Description

- Four-unit PWR located on the west coast of France
- Severe winter storm on December 27, 1999
- Units 1,2, and 4 operating at full power
- Unit 3 was refueling
- LOOP to units 2 and 4
- Flood water damaged the dike, failed internal barriers and entered Units 1 and 2

Blayais Flooding Event (1999)

Blayais Flooding Event (1999) Cont'd

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Selection of Dynamic Interactions During Blayais Flooding Event

No.	Time*	Element 1	Element 2	Interaction
1	0:00	Ext. Env.	Network	High winds down trees, damage power lines
3	0:30	Ext. Env.	Loc. Env.	Storm driven waves on top of storm surge and high tide overtop dyke, flood site
4	2:00	Ext. Env.	Network	High winds cause grid instability
5	2:00	Network	Plant	Grid instability leads to loss of 400 kV power to Units 2 and 4, reactor scram, EDGs start and load
6	2:30	Loc. Env.	Plant	Site flooding leads to partial loss of Unit 1 ESWS, loss of Unit 1 and Unit 2 LHSI and CSS
7	2:30	Plant Staff	Plant	Unit 2 400 kV is restored
8	3:00	Ext. Env.	Plant Staff	High water level alarm received by Unit 4
9	3:00	Plant Staff		High water alert not passed on to other units
10	4:20	Plant Staff	Plant	Unit 4 400 kV is restored
14	7:50	Plant Staff		Arrival of offsite personnel allows activation of Level 1 Emergency Plan
20	14:00	Plant Staff	Offsite Orgs.	Level 2 Emergency Plan activated for Unit 1; national emergency teams activated, discuss proposed shutdown strategy considering possibility of additional failures and Y2K complications

Blayais Flooding Event (1999) Cont'd

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Commentary

Interactions occurred within hours others within days

Timeframe information is important when developing a detailed dynamic model

Assuming a "game over" approach, might not be realistic. A dynamic analysis might provide additional insights

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Vandellos Turbine Fire (1989)

Event Description

- Gas cooled, natural uranium fueled, graphite moderated reactor located in Spain
- Reactor operating at 80% power
- Series of events after the ejection of 36 blades from Turbine
  - Ejected blades severed a pipe, spilling 4500 liters of lubricating oil in 55 seconds
  - Burning hydrogen ignited the lubricating oil
  - Burning oil damaged expansion joints, spilling significant amounts of sea water, resulting in a flooding in the turbine building
  - Burning oil spread on top of the water
  - Water reached the reactor building
  - Turbo blowers and feedwater pumps for the heat exchangers failed
  - 2 hours to regain auxiliary feedwater flow to main heat exchangers
  - 6 hours to extinguish the fire

Selection of Dynamic Interactions During Vandellos Turbine Fire

No.	Time	Element 1	Element 2	Interaction
1	21:39	Plant	Plant Staff	Turbine blades ejected
2	21:40 (00:01)	Plant Staff	Plant	1. Unusual vibrations detected 2. Vibration alarm and turbine trip annunciation 3. Fire observed in the turbine 4. Manual trip of reactor
3	21:40 (00:01)	Plant	Internal Hazard (fire)	1. 4500 lts of oil spilled from severed pipe 2. Hydrogen excursion ignited the lubricating oil (seal failure) 3. Sprinkler activated as designed, but did not control fire
4	21:40 (00:01)	Internal Hazard (Fire)	Internal Hazard (flood)	Fire caused expansion joint damage, spilling water from the circulating water system. Water collected in the basement of the turbine building. Sump pumps did not activate due to cable damage
5	21:40 (00:01)	Internal Hazard (Fire)	Plant Staff	Fire brigade called
13	4:00 (6:21)	Plant Staff	Plant	Fire extinguished
14	1:30 (36:00)		Staff	Cooling recovered

Vandellos Turbine Fire (Cont'd)

Vandellos Turbine Fire (1989) (Cont'd)

Commentary

Major challenge was the rapid, parallel development of multiple hazards scenarios

DPRA provides a framework allowing the treatment of these scenarios

To analyze these kind of scenarios, a high-fidelity model would be needed.

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Duane Arnold Loss of Offsite Power (2020) (Cont'd)

Event Description

- BWR Reactor, Mark I containment, located in Iowa
- On August 10, 2020, the plant experienced a loss of offsite power (LOOP) event due to high winds
- High winds caused damage to 6 offsite power sources
- LOOP caused a generator trip and automatic reactor scram
- EDGs provided power to safety-related busses
- Debris clogged the Train B Emergency Service Water strainer
- Damage to the Reactor, Turbine and FLEX Buildings

Selection of Dynamic Interactions During Duane Arnold Loss of Offsite Power

No.	Approx. Time (Interval)	Element 1	Element 2	Interaction
1	(0:00)	External Environment		High Winds Storm Derecho
2	11:38 (0:00)	Plant Staff		Entered abnormal operating procedures
3	12:35 (0:57)	Network	Plant	Grid perturbation caused the two EDGs ('A' and 'B' EDGs) to automatically start and run unloaded. HPCI and RCIC initiated automatically
4	12:46 (1:08)	Plant		Load reject and reactor scram
5	12:49 (1:11)	Network	Plant	LOOP caused a main generator trip on reverse power automatic reactor scram
6	12:58 (1:21)	Plant Staff		Licensee declared an unusual event
7	22:30 (11:52)	Plant Staff	Plant	Shutdown cooling initiated
8	22:40 (12:02)	Plant Staff	Plant	Operators bypass train B ESW strainer due to high differential plugging
10	11:26 (23:48)	Plant Staff	Plant	161 KV off-site power restored
12	13:12 (25:34)	Network	Plant	Safety bus A reenergized from offsite power
13	13:34 (25:56)	Network	Plant	Safety bus B reenergized from offsite power

Duane Arnold Loss of Offsite Power (2020)(Cont’d)

Duane Arnold Loss of Offsite Power (2020) (Cont'd)

Commentary

LOOP with and unavailable EDG that can be treated using conventional tools

If storm damage would have been more severe, plant staff actions would have been more challenging

Dynamic analysis would provide additional useful insights

Conclusions

- Completed a small-scale exploratory study, analyzing 5 nuclear events.
- Identified a number of interactions that
  - Appeared to be important in the evolution of the incidents
  - Appeared to be amenable to direct treatemnt in a DPRA
- Insights from this small-scale study indicate that the behaviors and interactions identified by conducting a simplified dynamic analysis can point towards other failures and responses that could be modeled in a conventional PRA.
- Insights might change as more events are reviewed

Next Steps

Analyze — Analyze additional events

Address — Address how the identified dynamic behaviors would be treated in a conventional PRA

Complete — Complete final report including detailed list of interactions

Questions

For further questions, please contact:
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