Modeling of Portable Equipment in PSA: History, Current Activities, and Challenges

N. Siu

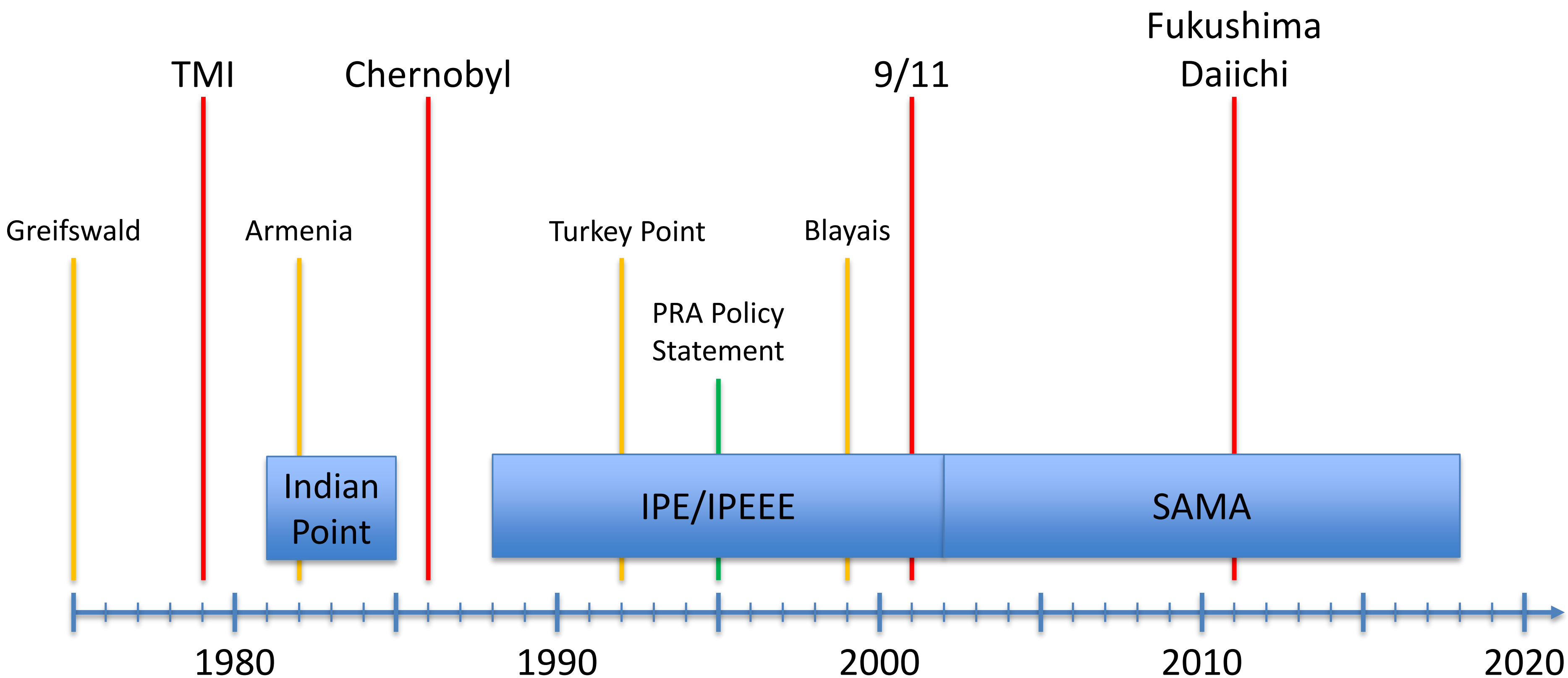
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research

WGRISK Annual Meeting
Paris, France
February 26-28, 2020

Outline

- History: past analyses and actual events
- FLEX: NRC activities
- Personal perspectives
  - Analysis considerations
  - Analysis technologies

Portable Equipment and Improvised Measures: Selected Events



Early Perspectives and Analyses

- ACRS (1955): nuclear “fire-fighters”
- Indian Point 3 PSA (1983)
- IPE/IPEEE (1988-2002) plant improvements:
  - Portable pumps (e.g., isolation condenser makeup)
  - Portable generators (battery chargers)
  - Portable fans (room cooling, smoke removal)

TABLE 1.6.2.2.1-13

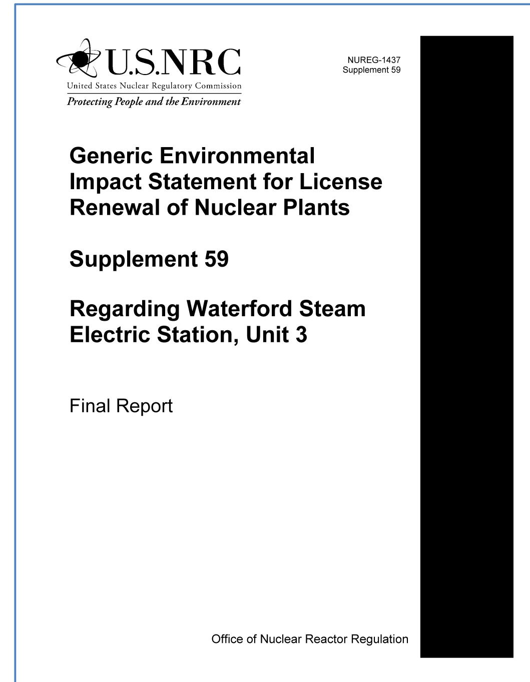
INDIAN POINT 3 OFFSITE POWER RECOVERY ACTIONS

Recovery Action	Estimated Action Time*
Energize 6.9 kV buses 5 and 6 from Buchanan 13.8 kV supply (if available)	5 - 10 minutes
Reset transfer trips and sectionalizing relays to reenergize Buchanan 138 kV or 13.8 kV supply from an available feeder	10 - 20 minutes
Start gas turbine generator unit 1	30 - 60 minutes
Start gas turbine generator units at Buchanan substation	30 - 60 minutes
Repair at least one 138 kV or 13.8 kV feeder to the station	2 - 24 hours
Provide auxilary portable generation equipment to the station	24 - 72 hours

*This is not an estimate of total response time which depends upon the precise event scenario. Rather, it is an estimate of the time required to effect the given action once that action has been identified as appropriate (i.e., it is approximately equal to total response time minus recognition and evaluation time).

SAMA Analyses

- Identify and assess potentially cost-beneficial severe accident management alternatives*
- Staff reviews: plant-specific supplements to NUREG-1437 (2002-2018)
- Alternatives include portable:
  - Generators (battery chargers, direct power)
  - Pumps
  - Air compressors
  - Fans
- Typically bounding analyses (no operator errors) to maximize potential risk reduction (CDF, population dose, offsite economic cost)
- Alternatives sometimes not considered or screened because:
  - portable equipment already implemented (FLEX)
  - intent covered (e.g., manual control of TDAFW)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NUREG-1437
Supplement 59

Generic Environmental Impact Statement for License Renewal of Nuclear Plants

Supplement 59

Regarding Waterford Steam Electric Station, Unit 3

Final Report

Office of Nuclear Reactor Regulation

*Broader analyses also consider environmental impact of license renewal (e.g., air quality and noise effects)

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Recent NRC FLEX Activities

- Focus on key Risk-Informed Decision Making (RIDM) programs
  - Significance Determination Process (SDP)
  - Notices of Enforcement Discretion (NOEDs)
  - License Amendment Requests (LARs)
- Staff engaged with industry
- Challenges
  - Access to operational experience (OpE) data
  - HRA methods for challenging actions
  - Incorporating FLEX actions into NRC SPAR models (success criteria, modeling variations, …)

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Recent NRC FLEX Activities: HRA (1 of 2)

- Integrated Human Event Analysis System (IDHEAS)
  - Finalize general methodology (IDHEAS-G)
  - Event and condition assessment tool (IDHEAS-ECA) now available: RIL-2020-02 (ML20016A481)
  - Under development: IDHEAS-DATA (documentation)
- Expert elicitation
  - 2018 Workshop
    - 6 experts (NRC and industry)
    - Formal process (SSHAC Level 2+/3-)
    - 2 scenarios (FLEX- and non-FLEX designed), 5 FLEX actions
    - Largest HEP: Extended Loss of AC Power (ELAP) declaration
    - Important PIFs: training, scenario familiarity, FSG entry conditions

Recent NRC FLEX Activities: HRA (2 of 2)

- Expert elicitation (cont.)
  - 2019 Workshop
    - 6 experts (NRC and industry)
    - Prioritized Industry Support
    - Developed several FLEX scenarios
      - 2 Site visits (PWR and BWR)
      - Both FLEX and non-FLEX scenarios
    - Used the IDHEAS-ECA tool
    - Developed HEPs for several FLEX actions in specific scenarios

Recent NRC FLEX Activities: SPAR Models (1 of 3)

- Ongoing incorporation into Standardized Plant Analysis Risk (SPAR) models
  - SPAR models
    - Maintained for all U.S. operating NPPs (Level 1, at-power)
    - Some models address fire, external hazards, low power and shutdown operations, Level 2
    - Many staff uses; principal applications: Reactor Oversight Program (ROP) and Accident Sequence Precursor (ASP) Program
  - FLEX scenarios are added when actions are proceduralized.
  - FLEX added to all hazard categories where applicable.
  - Most SPAR models updated with modeling variations (affecting results).

Recent NRC FLEX Activities: SPAR Models (2 of 3)

- Results and insights to date:
  - FLEX strategies and equipment can provide alternative success paths when called by plant procedures
  - Effectiveness strongly affected by modeling choices: success criteria, mission times, accident sequence termination
  - Effectiveness is plant specific; depends on
    - Percentage of contribution of SBO CDF w/o FLEX
    - AC power recovery capabilities, AC power recovery model assumptions, and failure probabilities for FLEX equipment (running beyond the first 24 hours)
  - Effectiveness varies according to hazard category and initiating event

Recent NRC FLEX Activities: SPAR Models (3 of 3)

- Challenges
  - Operator action modeling and HEP calculations
  - Failure data for portable equipment
  - Success criteria
    - Sequence success criteria (declaration of success)
    - Equipment success criteria
  - Extension to shutdown operations
  - Justification and variations (by event/hazard type) for time windows currently apportioned for various FLEX strategies
  - Maturity of newly created FLEX procedure steps (for MCR and for local actions)
  - Potential downsides to declaration of ELAP

Recent NRC FLEX Activities: Further Reading

- M. Humberstone, “Crediting Mitigating Strategies in Risk-Informed Decision Making,” June 28, 2017. (ML17174B290)
- M. Montecalvo, , “Crediting Mitigating Strategies in Regulatory Applications,” August 16, 2018. (ML18228A834)
- J. Xing, M. Kichline, J. Hughey, and M. Humberstone, “The use of expert judgment to support human reliability analysis of implementing FLEX equipment,” *Proceedings ANS International Meeting on Probabilistic Safety Assessment (PSA 2019)*, Charleston, SC, April 28-May 3, 2019. (ML19023A508)
- M. Humberstone, “Crediting FLEX Equipment in Risk Assessments: Case Study,” July 31, 2019. (ML19228A063)
- M. Montecalvo, M. Humberstone, and J. Xing, “Role of human reliability analysis in post-Fukushima risk-informed decision making,” ESREL 2019 (ML19080A109).

FLEX Analysis: Some Considerations

- Affected by intended purpose
  - Bounding analysis of potential benefits (no human error)
  - Simple risk-informed applications (conservative "Game Over")
  - Emergency response planning and training (realistic)
- Context: situation likely to be challenging
  - Failures of preferred or portable equipment
  - Possibly missing/misleading indications
  - Possibly unclear effectiveness
  - Possibly unforeseen situation
  - Possibly damaged crew confidence

Analyst caution: beware omniscient, PRA-model informed point of view

- Potential downsides (real or perceived)
  - Declaration of Extended Loss of AC Power (ELAP)
  - RCS depressurization
- Potential changes over time
  - Equipment qualification
  - Crew deep knowledge
  - Technology advances and potential vulnerabilities

More Analysis Considerations*

Scenario Dynamics

- Progressive deterioration of situation
- Multiple "shocks" over time
- Needed enabling actions
  - Post-hazard safety surveys/inspections
  - Radiation measurements
  - Pre-firefighting actions (e.g., N_2 inerting)
  - Firefighting to allow access

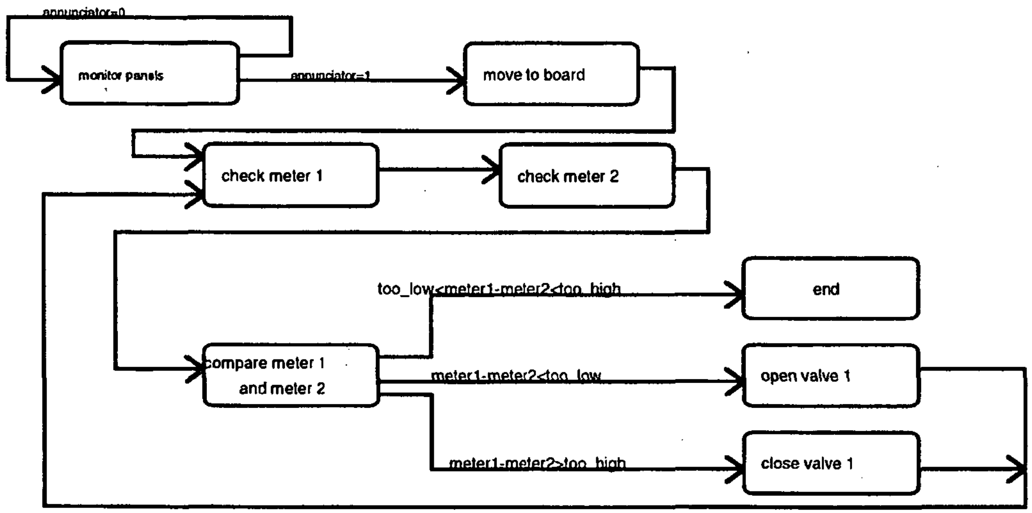
Crew Workarounds

- Bypass damaged (real or suspected) instrument lines
- Temporary cables
- Scavenged batteries
- Courier systems
- Break/bypass fire barriers
- Trial and error problem solving
- Bypass safety interlocks

*Not FLEX-specific but relevant to challenging scenario response (including FLEX)

Perspectives on Analysis Technology

- Behavioral (non-cognitive execution): well suited for task-analysis simulation



NUREG/CR-6159

- Advanced modeling: see wargames, security-related simulations ("discrete event," "object-oriented")
- Early resources:
  - A. Siegel, et al., "Maintenance Personnel Performance Simulation (MAPPS) Model: Summary Description," NUREG/CR-3626, Vol. 1, 1984.
  - M.T. Lawless, K.R. Laughery, and J.J. Persensky, "Using Micro Saint to Predict Performance in a Nuclear Power Plant Control Room: A Test of Validity and Feasibility," NUREG/CR-6159, 1995.

Summary

- Long history: successful use of portable equipment in actual events, credit in analyses
- NRC is actively engaged in efforts to appropriately credit FLEX in current risk-informed applications
- Simple analyses can be useful for some applications
- Detailed analyses (e.g., using simulation) are likely to be feasible and useful; need to account for observations from actual events

Acknowledgments

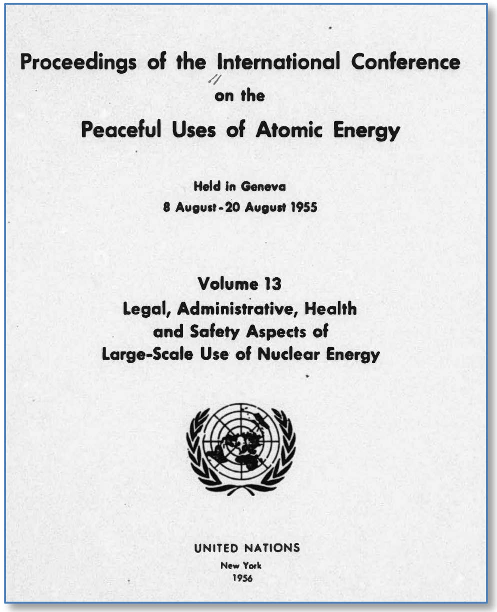
Thanks to Matthew Humberstone, Selim Sancaktar, and Jing Xing for their input to this presentation.

BACKUP SLIDES

Very Early Vision

> *"With all the inherent safeguards that can be put into a reactor, there is still no fool-proof system. Any system can be defeated by a great enough fool. The real danger occurs when a false sense of security causes a relaxation of caution."*
>
> - C.R. McCullough, M.M. Mills, and E. Teller, "The Safety of Nuclear Reactors"

- Specific concerns
  - Nuclear runaway
  - Delayed energy production
  - Chemical reactions
- Features for decay heat removal
  - Standby gravity flow/natural convection emergency cooling system
  - Standby emergency services (analogous to fire-fighters)
  - Standby forced convection cooling (special power supply, special separate piping)



Proceedings of the International Conference
on the
Peaceful Uses of Atomic Energy

Held in Geneva
8 August-20 August 1955

Volume 13
Legal, Administrative, Health
and Safety Aspects of
Large-Scale Use of Nuclear Energy

UNITED NATIONS
New York
1956

Example Events Before 3/11

- Major External Events
  - Hurricane Andrew/Turkey Point 3&4 (1992)
  - Winter Storm Martin/Blayais 1&2 (1999)

Onsite damage, loss of site access, offsite damage; portable fire pumps, debris removal

- Major Internal Fires
  - Greifswald 1 (1975)
  - Armenia 1&2 (1982)

Loss of power and control, smoke, explosions (A); temporary cables

https://commons.wikimedia.org/wiki/File:Metsamor_nuclear_power_plant,_cooling_towers_(Armenia,_June_2015).jpg

- Lesser events
  - San Onofre 1 (1982): submersible pump for intake structure
  - Diablo Canyon (2000): generator for switchyard battery charger
- Non-Nuclear Events
  - Northridge Earthquake, M 6.7 (1994)
  - Kobe Earthquake, M 6.9 (1995)

Facility and infrastructure damage, fires, emergency service demands; portable generators, pre-planning, workarounds

FLEX HRA Elicitation (1)

- 2018 workshop
- Participants
  - 3 NRC staff, 3 industry experts
  - Expertise: PRA/HRA, implementation/audits of FLEX strategies, use of portable equipment, maintenance operations
- Process Guidance: NRC White Paper (ML16287A734)
- Objectives
  - Quantify HEPs for a few typical actions using FLEX
  - Identify unique PSF attributes
  - Assess impact of PSFs on HEPs
- Outcomes
  - Definition of FLEX-designed and non-FLEX designed scenarios
  - HEP distributions for 5 actions with justifications
  - FLEX-specific PSFs with attributes
  - Effect of PSFs on HEPs

FLEX HRA Elicitation (2)

- Scenarios
  - Non-FLEX designed: 1 DG OOS (maintenance), LOOP, SBO due to DG failure, nominal conditions
  - FLEX-designed: SBO caused by high wind and flooding (affects access, visibility, debris location)
- Actions
  - Transport, connect, operate portable generators
  - Transport, connect, operate portable pumps
  - Refill storage tank with alternate sources
  - Declare ELAP
  - Deep DC load shed

FLEX HRA Elicitation (3)

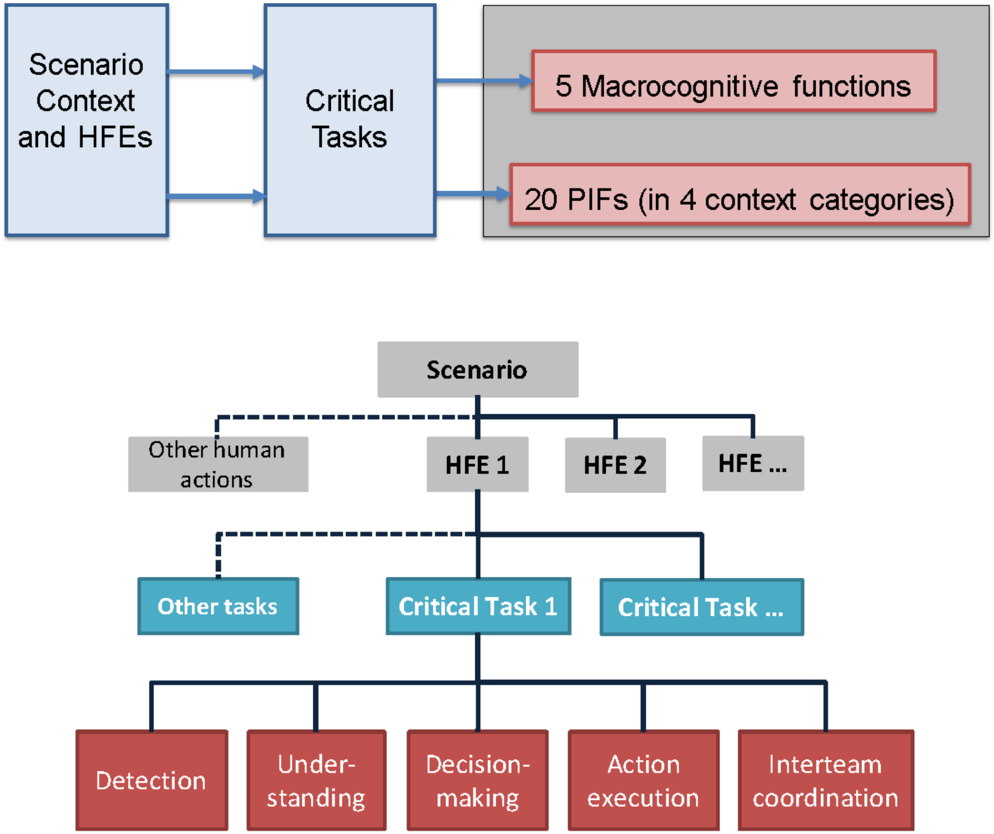
- Challenging context
  - System and environment
    - Environmental factors
    - Information
    - Tools and parts
    - Ergonomics (indications and controls)

    (Environmental factors, Information: Scenario-specific in analysis)
  - Personnel and organization
    - Training
    - Procedure
    - Teamwork factors

    (Training, Procedure: Scenario-specific in analysis)
  - Tasks
    - Scenario familiarity
    - Task complexity
    - Multitasking
    - Mental fatigue and stress
    - Physical demands

    (Scenario familiarity, Task complexity: Scenario-specific in analysis)

IDHEAS-ECA: Overview



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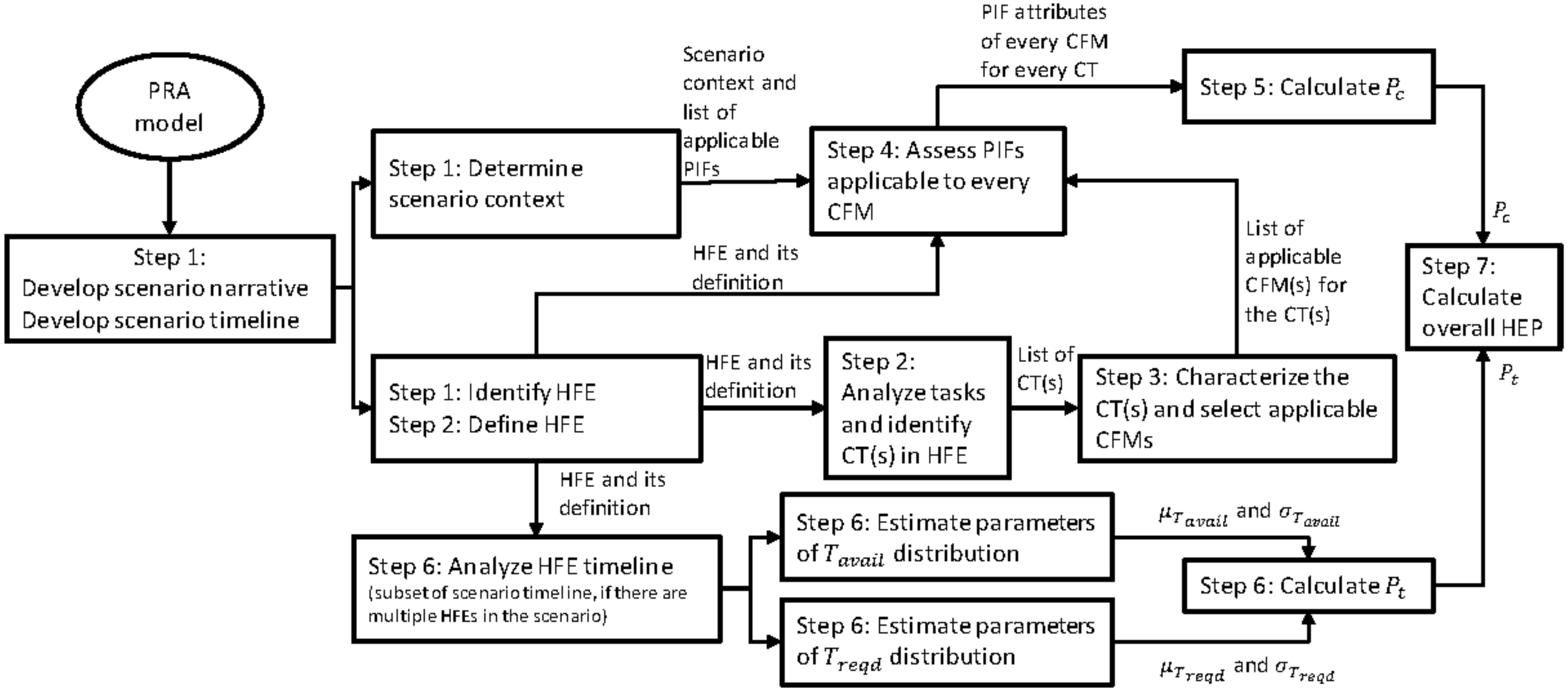
IDHEAS-ECA: Process



CFM = cognitive failure mode
CT = critical task
HEP = human error probability
HFE = human failure event
PIF = performance-influencing factor
PRA = probabilistic risk assessment

P_c = error probability due to CFMs
P_t = error probability due to uncertainty in T_{avail} and T_{reqd}
T_{avail} = time available
T_{reqd} = time required
$\mu_{T_{avail}}$ and $\sigma_{T_{avail}}$ = mean and standard deviation of T_{avail}
$\mu_{T_{reqd}}$ and $\sigma_{T_{reqd}}$ = mean and standard deviation of T_{reqd}

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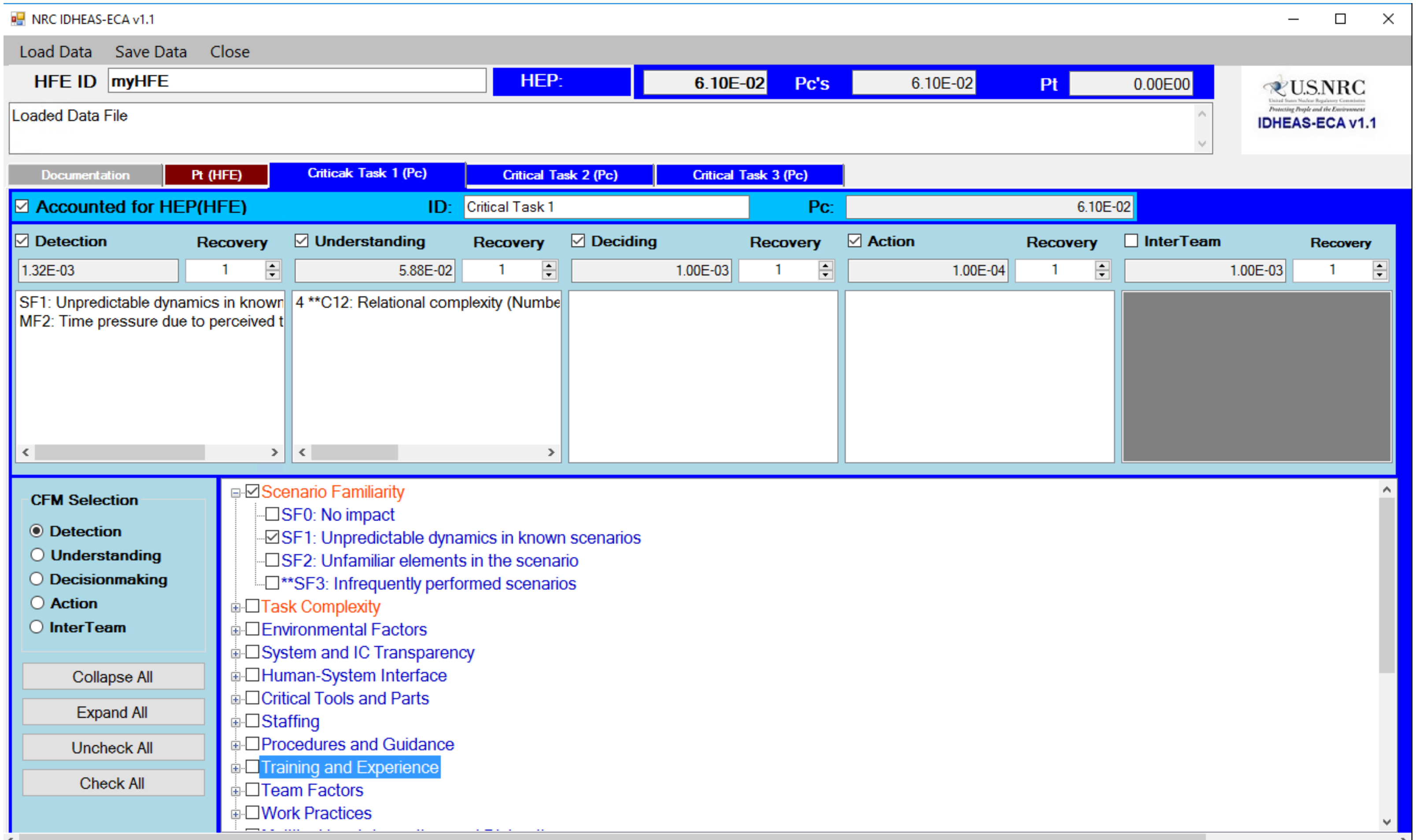
IDHEAS-ECA Software Tool* (1)



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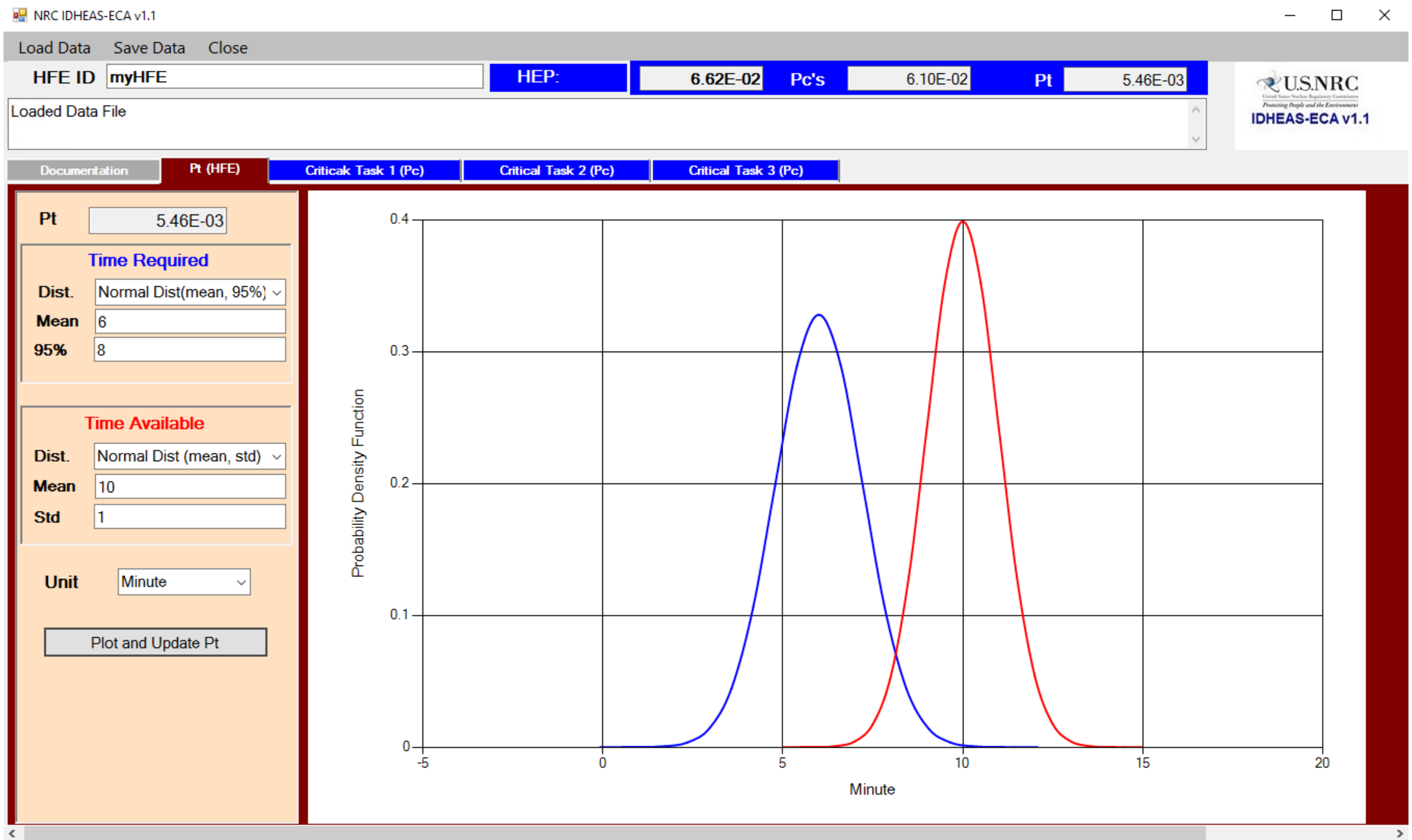
IDHEAS-ECA Software Tool* (2)



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SACADA*

SACADA 2 - NRCDOMAIN\YJC1

Author | Debrief Tasks | Crew Notebook | Administration | Options | Help

Authoring | Debrief - RST 219.10-1B

Open | Browse | Import | Save | Save As | Crew 1B | Info | Report | Status

Position	Impact	Name	Timer	Status	Observe Behavior (comment)	Description
		RST 219.10				
		1A SG Faulted/Ruptured	00:00:00			
CREW	Significant	Determines Primary to Secondary leakage in 1A SG	00:00:00	SAT		The determination should be completed within 2 minutes after the SG rupture.
US	Significant	Determines Primary to Secondary leakage is > CCP capacity and directs a Reactor Trip and Safety Injection		UNSAT	Took 3 minutes to complete.	Need to be done in 2 minutes
US	Safety Significant	Enters 0POP05-EO-EO00 and Directs/ Performs Immediate Actions		SAT		
CREW	Significant	Isolates AFW to 1A SG when level reaches 14% NR		SAT		
CREW	Significant	Performs actions of 0POP05-EO-EO00 until transition to 0POP05-EO-EO30		SAT		
SM	Safety Significant	Declares an ALERT due to FA1 EAL-3 (SGTR > CCP Capacity)		SAT		
CREW	Safety Significant	Transitions to 0POP05-EO-EO30 and Identifies and Isolates 1A SG		SAT		
CREW	Significant	Determines that 1A SG is faulted (Safety is OPEN)		SAT		
US	Safety Significant	Transitions to 0POP05-EO-EO20 and isolates the 1A SG		SAT		
SM	Safety Significant	Declares a SITE AREA EMERGENCY due to FS1 EAL-3		SAT		
US	Safety Significant	Transitions back to 0POP05-EO-EO30 Step 1		SAT		
CREW	Other	Selects the Target Temperature and performs cooldown in 0POP05-EO-EO30		SAT		
CREW	Safety Significant	Determines that after the cooldown in 0POP05-EO-EO30 the 1A SG pressure lowers to less than 250 psig above intact SGs and transitions to 0POP05-EO-EC31		SAT		
CREW	Other	Resets various actuations and establishes IA to the Containment		SAT		
CREW	Other	Energizes MCCs and DP panels per Addendum 1		SAT		
CREW	Other	Resets sequencer Mode I logic per Addendum 2		SAT		
CREW	Significant	Establishes Spent Fuel Pool Cooling		SAT		
CREW	Other	Verifies ALL 13.8 and 4.16 KV buses energized from Off-Site		SAT		

Need to be done in 2 minutes

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Some Challenging Fires and Recoveries

Date	Plant	Short Description	Beyond Procedures/ Training? [1]
3/22/1975	Browns Ferry 1 & 2	**Multi-unit cable fire**; multiple systems lost, spurious operations; non-proceduralized recovery.	Yes
12/7/1975	Greifswald 1	Electrical cable fire; station blackout (**SBO**), 5 hr loss of normal core cooling, loss of coolant; recovered with cross-tie with Unit 2.	Probably [2]
12/31/1978	Beloyarsk 2	Turbine lube oil fire , **collapsed turbine building roof, main control room (MCR) damage**, secondary fires; extinguished in 22 hours; damage to multiple safety systems and instrumentation.	Probably [2, 3]
10/15/1982	Armenia 1 & 2	Electrical cable fire (multiple locations), smoke in Unit 1 MCR**, secondary explosions and fire; SBO**, loss of instrumentation and reactor control; recovery using temporary cable.	Yes
10/19/1989	Vandellos 1	Turbine failure, **burning oil cascaded down to lower floors**. Smoke in MCR. **Turbine and reactor building flooded; recovery actions in darkened and smoke filled rooms.**	Partially [4]
10/11/1991	Chernobyl 2	Turbine failure and fire, **collapsed turbine building roof**; loss of generators, loss of feedwater; makeup from seal water supply.	Yes
3/31/1993	Narora 1	Turbine failure, explosion and fire, **smoke forced abandonment of shared MCR; SBO, loss of instrumentation**; shutdown cooling pump energized 17 hours later.	Yes

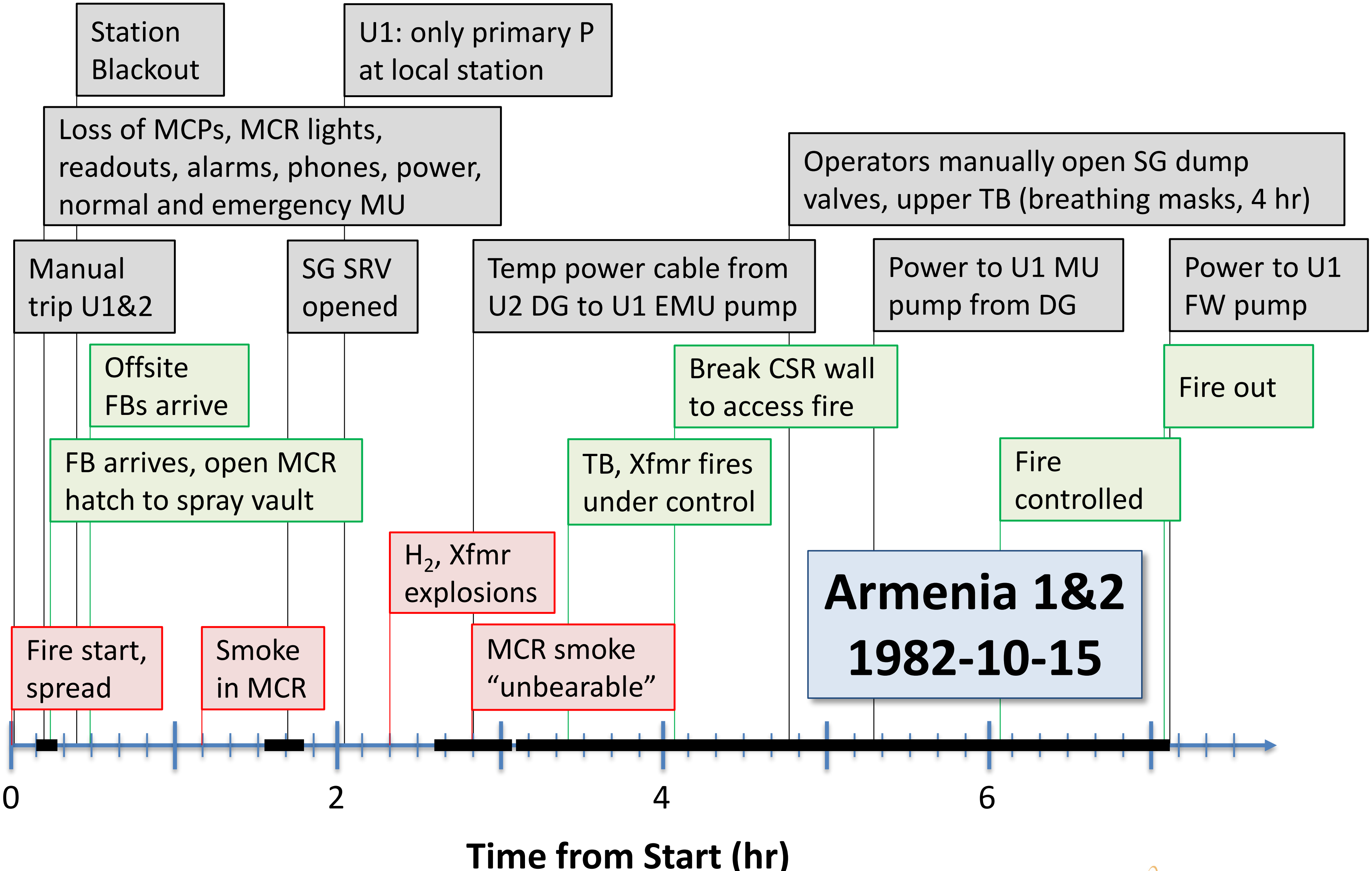
Notes on basis:

[1] "Yes" indicates explicit mention in NUREG/CR-6738

[2] Extensive losses (safety systems, power, control)

[3] Per NUREG/CR-6738, "…reactor was saved mainly by good luck."

[4] No specific written procedures; operator action based on 15 years experience in plant operations, periodic training on auxiliary feedwater control.


Station Blackout
U1: only primary P at local station
Loss of MCPs, MCR lights, readouts, alarms, phones, power, normal and emergency MU
Operators manually open SG dump valves, upper TB (breathing masks, 4 hr)
Manual trip U1&2
SG SRV opened
Temp power cable from U2 DG to U1 EMU pump
Power to U1 MU pump from DG
Power to U1 FW pump
Offsite FBs arrive
Break CSR wall to access fire
Fire out
FB arrives, open MCR hatch to spray vault
TB, Xfmr fires under control
Fire controlled
H_2, Xfmr explosions
Armenia 1&2
1982-10-15
Fire start, spread
Smoke in MCR
MCR smoke "unbearable"
0
2
4
6
Time from Start (hr)

Equipment Qualification

- January 6, 2010: Diesel Fuel Oil Transfer Pump FO-37 inoperable (local area flooding)
- June 24, 2010: portable back up pump found to be incorrect for application.
  - Discovered by engineering evaluation.
  - Subsequent test (August 30): pump diaphragm ruptured during functional test
  - Pump had been in place since March 29, 1994.
- Root cause: failure to perform appropriate design change evaluation (LER 285/2010-005-R01)

NRC FORM 366 (9-2007) U.S. NUCLEAR REGULATORYCOMMISSION

LICENSEE EVENT REPORT (LER)

(See reverse for required number of digits/characters for each block)

APPROVED BY OMB: NO. 3150-0104 EXPIRES: 08/31/2010

Estimated burden per response to comply with this mandatory collection request: 80 hrs. Reported lessons learned are incorporated into the licensing process and fed back to industry. Send comments regarding burden estimate to the Records and FOIA/Privacy Service Branch (T-5 F52), U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by internet e-mail to infocollects@nrc.gov, and to the Desk Officer, Office of Information and Regulatory Affairs, NEOB-10202, (3150-0104), Office of Management and Budget, Washington, DC 20503. If a means used to impose an information collection does not display a currently valid OMB control number, the NRC may not conduct or sponsor, and a person is not required to respond to, the information collection.

1. FACILITY NAME	2. DOCKET NUMBER	3. PAGE
Fort Calhoun Station	05000285	1 OF 3

4. TITLE: Inoperability of the Emergency Diesel Generator Fuel Oil Transfer System

5. EVENT DATE			6. LER NUMBER			7. REPORT DATE			8. OTHER FACILITIES INVOLVED	
MONTH	DAY	YEAR	YEAR	SEQUENTIAL NUMBER	REV NO	MONTH	DAY	YEAR	FACILITY NAME	DOCKET NUMBER 05000
1	6	2010	2010	- 005 -	01	1	26	2011	FACILITY NAME	05000

9. OPERATING MODE: 1

10. POWER LEVEL: 100

11. THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR §: (*Check all that apply*)

☐ 20.2201(b)	☐ 20.2203(a)(3)(i)	☐ 50.73(a)(2)(i)(C)	☐ 50.73(a)(2)(vii)
☐ 20.2201(d)	☐ 20.2203(a)(3)(ii)	☐ 50.73(a)(2)(ii)(A)	☐ 50.73(a)(2)(viii)(A)
☐ 20.2203(a)(1)	☐ 20.2203(a)(4)	☐ 50.73(a)(2)(ii)(B)	☐ 50.73(a)(2)(viii)(B)
☐ 20.2203(a)(2)(i)	☐ 50.36(c)(1)(i)(A)	☐ 50.73(a)(2)(iii)	☐ 50.73(a)(2)(ix)(A)
☐ 20.2203(a)(2)(ii)	☐ 50.36(c)(1)(ii)(A)	☐ 50.73(a)(2)(iv)(A)	☐ 50.73(a)(2)(x)
☐ 20.2203(a)(2)(iii)	☐ 50.36(c)(2)	☐ 50.73(a)(2)(v)(A)	☐ 73.71(a)(4)
☐ 20.2203(a)(2)(iv)	☐ 50.46(a)(3)(ii)	☐ 50.73(a)(2)(v)(B)	☐ 73.71(a)(5)
☐ 20.2203(a)(2)(v)	☐ 50.73(a)(2)(i)(A)	☐ 50.73(a)(2)(v)(C)	☐ OTHER
☐ 20.2203(a)(2)(vi)	X 50.73(a)(2)(i)(B)	☐ 50.73(a)(2)(v)(D)	Specify in Abstract below or in NRC Form 366A

12. LICENSEE CONTACT FOR THIS LER

FACILITY NAME	TELEPHONE NUMBER (*include Area Code*)
Richard Acker	402-533-6561

13. COMPLETE ONE LINE FOR EACH COMPONENT FAILURE DESCRIBED IN THIS REPORT

CAUSE	SYSTEM	COMPONENT	MANU-FACTURER	REPORTABLE TO EPIX	CAUSE	SYSTEM	COMPONENT	MANU-FACTURER	REPORTABLE TO EPIX

14. SUPPLEMENTAL REPORT EXPECTED	15. EXPECTED SUBMISSION DATE	MONTH	DAY	YEAR
Yes (*If yes, complete 15. EXPECTED SUBMISSION DATE*) NO XX				

ABSTRACT (*Limit to 1400 spaces, i.e., approximately 15 single-spaced typewritten lines*)

Diesel Fuel Oil Transfer Pump FO-37 and its credited portable back-up pump were inoperable on January 6-7, 2010. On January 6, 2010, FO-37 was rendered inoperable due to local area flooding caused by the rupture of FP-772, "Service Building Fire Sprinkler Isolation Valve". A function of FO-37 is to transfer diesel fuel between "Diesel Fuel Oil Storage Tanks" FO-10 and FO-1. On June 24, 2010, an engineering evaluation determined that the credited portable back up pump to FO-37 was not the correct pump for the application and would not transfer diesel fuel oil from FO-10 to FO-1 as intended. Since both pumps (FO-37 and the credited portable back-up pump) were inoperable this is reportable in accordance with 10 CFR 50.73(a)(2)(i)(B).

A root cause analysis determined there was a failure to perform an appropriate design change evaluation for maintaining diesel fuel oil transfer system capability as required by Technical Specification Amendment 162, dated March 29, 1994. The originally credited portable back-up pump was replaced with a new portable pump that has the capability to transfer diesel fuel oil between tanks FO-10 and FO-1. The appropriate procedures were revised to address the pump replacement.

NRC FORM 366 (9-2007) PRINTED ON RECYCLED PAPER

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