NUREG/CP-0303 EPRI 3002005205
Volume 4 of 5

Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)-2012

Volume 4
Module 4: Human Reliability Analysis (HRA)

Based on the Joint
NRC-RES/EPRI Training Workshops
Conducted in 2012

Weeks of July 16 and September 24, 2012

Bethesda, MD

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94304

AVAILABILITY OF REFERENCE MATERIALS IN NRC PUBLICATIONS

NRC Reference Material

As of November 1999, you may electronically access NUREG-series publications and other NRC records at NRC's Library at www.nrc.gov/reading-rm.html. Publicly released records include, to name a few, NUREG-series publications; *Federal Register* notices; applicant, licensee, and vendor documents and correspondence; NRC correspondence and internal memoranda; bulletins and information notices; inspection and investigative reports; licensee event reports; and Commission papers and their attachments.

NRC publications in the NUREG series, NRC regulations, and Title 10, "Energy," in the *Code of Federal Regulations* may also be purchased from one of these two sources.

1. **The Superintendent of Documents**
   U.S. Government Publishing Office
   Mail Stop IDCC
   Washington, DC 20402-0001
   Internet: bookstore.gpo.gov
   Telephone: (202) 512-1800
   Fax: (202) 512-2104

2. **The National Technical Information Service**
   5301 Shawnee Rd., Alexandria, VA 22312-0002
   www.ntis.gov
   1-800-553-6847 or, locally, (703) 605-6000

A single copy of each NRC draft report for comment is available free, to the extent of supply, upon written request as follows:

Address: **U.S. Nuclear Regulatory Commission**
Office of Administration
Publications Branch
Washington, DC 20555-0001
E-mail: distribution.resource@nrc.gov
Facsimile: (301) 415-2289

Some publications in the NUREG series that are posted at NRC's Web site address www.nrc.gov/reading-rm/doc-collections/nuregs are updated periodically and may differ from the last printed version. Although references to material found on a Web site bear the date the material was accessed, the material available on the date cited may subsequently be removed from the site.

Non-NRC Reference Material

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, transactions, *Federal Register* notices, Federal and State legislation, and congressional reports. Such documents as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings may be purchased from their sponsoring organization.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at—

The NRC Technical Library
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852-2738

These standards are available in the library for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from—

American National Standards Institute
11 West 42nd Street
New York, NY 10036-8002
www.ansi.org
(212) 642-4900

Legally binding regulatory requirements are stated only in laws; NRC regulations; licenses, including technical specifications; or orders, not in NUREG-series publications. The views expressed in contractor prepared publications in this series are not necessarily those of the NRC.

The NUREG series comprises (1) technical and administrative reports and books prepared by the staff (NUREG–XXXX) or agency contractors (NUREG/CR–XXXX), (2) proceedings of conferences (NUREG/CP–XXXX), (3) reports resulting from international agreements (NUREG/IA–XXXX), (4) brochures (NUREG/BR–XXXX), and (5) compilations of legal decisions and orders of the Commission and Atomic and Safety Licensing Boards and of Directors' decisions under Section 2.206 of NRC's regulations (NUREG–0750).

Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)-2012

NRC-RES/EPRI Fire PRA Workshop
Volume 4: Module 4: HRA

NUREG/CP-0303
Volume 4 of 5

EPRI 3002005205

Manuscript Completed: July 2015
Date Published: April 2016

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research (RES)
Washington, DC 20555-0001

Electric Power Research Institute (EPRI)
3420 Hillview Avenue
Palo Alto, CA 94304

U.S. NRC-RES Project Manager
M. H. Salley

EPRI Project Manager
A. Lindeman

ORGANIZATION THAT PREPARED THIS DOCUMENT:

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

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

COURSE TRAINING INSTRUCTORS AND PROJECT MANAGERS

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research (RES)
Washington, DC 20555-0001

Susan Cooper – Module 4 HRA

Gabriel Taylor – Module 2 Electrical Analysis

Sandia National Laboratories (SNL)
1515 Eubank SE
Albuquerque, NM 87185

Steven Nowlen – Module 3 Fire Analysis

Jeff LaChance – Module 1 PRA

National Institute of Standards and Technology (NIST)
100 Bureau Dr.
Gaithersburg, MD 20899

Kevin McGrattan – Module 5 Adv. Fire Modeling

Electric Power Research Institute (EPRI)
3420 Hillview Avenue
Palo Alto, CA 94303

Stuart Lewis – Module 4 HRA

Science Applications International Corp. (SAIC)

1671 Dell Ave, Suite 100
Campbell, CA 95008

Bijan Najafi

Francisco Joglar-Biloch – Module 3 Fire Analysis

Dan Funk (EDAN Engineering) – Module 2 Electrical

Richard Anoba (Anoba Consulting Services) –Module 1 PRA

Erin Collins –Module 4 HRA

Fred Mowrer (California Polytechnic State University) – Module 5 Adv. Fire Modeling

Kendra Wright /Nicholas Melly
U.S. NRC-RES Project Managers

Ashley Lindeman
EPRI Project Manager

CITATIONS

This report was prepared by:

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research (RES)
Washington, DC 20555-0001

Principal Investigators:

F. Gonzalez
K. Hamburger
T. Rivera
P. Smith
D. Stroup
K. Wright

This report describes research sponsored jointly by the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research and EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)-2012, NRC-RES/EPRI Fire PRA Workshop, Volume 1: Overall Course and Module 1: PRA, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC 20555-0001, and Electric Power Research Institute, Palo Alto, CA, NUREG/CP-0303 and EPRI 3002005205.

ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research (RES) and the Electric Power Research Institute (EPRI) working under a memorandum of understanding (MOU) jointly conducted two sessions of the NRC– RES/EPRI Fire Probabilistic Risk Assessment (PRA) Workshop on July 16–20, 2012, and September 24–28, 2012, at the Bethesda Marriott in Bethesda, MD. The purpose of the workshop was to provide detailed, hands-on training on the fire PRA methodology described in the technical document, NUREG/CR-6850 (EPRI 1011989) entitled "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities." This fire PRA methodology document supports implementation of the risk-informed, performance-based rule in Title 10 of the *Code of Federal Regulations* (10 CFR) 50.48(c) endorsing National Fire Protection Association (NFPA) Standard 805, as well as other applications such as exemptions or deviations to the agency's current regulations and fire protection significance determination process (SDP) phase 3 applications.

RES and EPRI provided training in five subject areas related to fire PRA, namely: fire PRA, electrical analysis, fire analysis, fire human reliability analysis (HRA), and advanced fire modeling. Participants selected one of these subject areas and spent the duration of the course in that module. The HRA module reviewed guidance provided in NUREG-1921 (EPRI 1023001), "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines," while the fire modeling module reviewed the fire modeling guidance provided in NUREG-1934 (EPRI 1019195), "Nuclear Power Plant Fire Modeling Application Guide." For each technical area, the workshop also included a 1-day module introducing the fundamentals of the subject. The purpose of the fundamentals modules was to assist students without an extensive background in the technical area in understanding the in-depth training modules that followed. Attendance in the fundamentals modules was optional. The workshop's format allowed for in-depth presentations and practical examples directed toward the participant's area of interest.

This NUREG/CP documents both of the two sessions of the NRC-RES/EPRI Fire PRA Workshop delivered in 2012 and includes the slides and handout materials delivered in each module of the course as well as video recordings of the training that was delivered. This NUREG/CP can be used as an alternative training method for those who were unable to physically attend the training sessions. This report can also serve as a refresher for those who attended one or more training sessions and could also be useful preparatory material for those planning to attend future sessions.

<u>NRC Disclaimer:</u>

This document's text and video content are intended solely for use as training tools. No portions of their content are intended to represent NRC's conclusions or regulatory positions, and they should not be interpreted as such.

CONTENTS

ACKNOWLEDGMENTS

The authors of this report greatly appreciate the contributions made by instructors and students at the 2012 NRC-RES/EPRI Fire PRA Workshop.

In addition, we want to extend our gratitude to Tojuana Fortune-Grasty (NRC's publications specialist) and the NRC's printing specialist's team whose invaluable support and expertise were critical to ensuring the published report's quality. We also extend a special thanks and appreciation to Anita Aikins-Afful (RES/DRA administrative assistant) for providing the technical edit of this report.

ACRONYMS

ACB	Air-cooled Circuit Breaker
ACRS	Advisory Committee on Reactor Safeguards
AEP	Abnormal Event Procedure
AFW	Auxiliary Feedwater
AGS	Assistant General Supervisor
AOP	Abnormal Operating Procedure
AOV	Air Operated Valve
ASEP	Accident Sequence Evaluation Program
ATHEANA	A Technique for Human Event Analysis
ATS	Automatic Transfer Switch
ATWS	Anticipated Transient Without Scram
BAT	Boric Acid Tank
BNL	Brookhaven National Laboratory
BWR	Boiling-Water Reactor
CBDT	Cause-Based Decision Tree
CCDP	Conditional Core Damage Probability
CF	Cable (Configuration) Factors
CCPS	Center for Chemical Process Safety
CCW	Component Cooling Water
CDF	Core Damage Frequency
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CLERP	Conditional Large Early Release Probability
CM	Corrective Maintenance
CR	Control Room
CRS	Cable and Raceway (Database) System
CST	Condensate Storage Tank
CVCS	Chemical and Volume Control System
CWP	Circulating Water Pump
DC	Direct Current
ECCS	Emergency Core Cooling System
EDG	Emergency Diesel Generator
EDS	Electrical Distribution System
EF	Error Factor
EI	Erroneous Status Indicator
EOP	Emergency Operating Procedure
EPR	Ethylene-Propylene Rubber
EPRI	Electric Power Research Institute
ET	Event Tree
FEDB	Fire Events Database
FEP	Fire Emergency Procedure
FHA	Fire Hazards Analysis

FIVE	Fire-Induced Vulnerability Evaluation (EPRI TR 100370)
FMRC	Factory Mutual Research Corporation
FPRAIG	Fire PRA Implementation Guide (EPRI TR 105928)
FRSS	Fire Risk Scoping Study (NUREG/CR-5088)
FSAR	Final Safety Analysis Report
HCR	Human Cognitive Reliability
HEAF	High Energy Arcing Fault
HEP	Human Error Probability
HFE	Human Failure Event
HPI	High-Pressure Injection
HPCI	High-Pressure Coolant Injection
HRA	Human Reliability Analysis
HRR	Heat Release Rate
HTGR	High-Temperature Gas-cooled Reactor
HVAC	Heating, Ventilation, and Air Conditioning
ICDP	Incremental Core Damage Probability
ILERP	Incremental Large Early Release Probability
INPO	Institute for Nuclear Power Operations
IPE	Individual Plant Examination
IPEEE	Individual Plant Examination of External Events
IS	Ignition Source
ISLOCA	Interfacing Systems Loss of Coolant Accident
KS	Key Switch
LCO	Limiting Condition of Operation
LERF	Large Early Release Frequency
LFL	Lower Flammability Limit
LOC	Loss of Control
LOCA	Loss-of-Coolant Accident
LPG	Liquefied Petroleum Gas
LP/SD	Low Power and Shutdown
LWGR	Light-Water-cooled Graphite Reactors (Russian design)
MCB	Main Control Board
MCC	Motor Control Center
MCR	Main Control Room
MG	Motor-Generator
MFW	Main Feedwater
MOV	Motor-Operated Valve
MQH	McCaffrey, Quintiere, and Harkleroad's Method
MS	Main Steam
MSIV	Main Steam Isolation Valve
NC	No Consequence
NEI	Nuclear Energy Institute
NEIL	Nuclear Electric Insurance Limited
NFPA	National Fire Protection Association
NPP	Nuclear Power Plant

NPSH	Net Positive Suction Head
NQ cable	Non-Qualified (IEEE-383) cable
NRC	U.S. Nuclear Regulatory Commission
ORE	Operator Reliability Experiments
P&ID	Piping and Instrumentation Diagram
PE	Polyethylene
PM	Preventive Maintenance
PMMA	Polymethyl Methacrylate
PORV	Power-Operated Relief Valve
PRA	Probabilistic Risk Assessment
PSF	Performance Shaping Factor
PTS	Pressurized Thermal Shock
PVC	Polyvinyl Chloride
PWR	Pressurized Water Reactor
Q cable	Qualified (IEEE-383) cable
RBMK	Reactor Bolshoy Moshchnosty Kanalny (high-power channel reactor)
RCIC	Reactor Core Isolation Cooling
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RDAT	Computer program for Bayesian analysis
RES	Office of Nuclear Regulatory Research (at NRC)
RHR	Residual Heat Removal
RI/PB	Risk-Informed / Performance-Based
RPS	Reactor Protection System
RWST	Refueling Water Storage Tank
SCBA	Self-Contained Breathing Apparatus
SDP	Significance Determination Process
SGTR	Steam Generator Tube Rupture
SI	Safety Injection
SMA	Seismic Margin Assessment
SNPP	Simplified Nuclear Power Plant
SO	Spurious Operation
SOV	Solenoid Operated Valve
SPAR-H	Standardized Plant Analysis Risk HRA
SRV	Safety Relief Valve
SSD	Safe Shutdown
SSEL	Safe Shutdown Equipment List
SST	Station Service Transformer
SUT	Start-up Transformer
SW	Service Water
SWGR	Switchgear
T/G	Turbine/Generator
T-H	Thermal Hydraulic
THERP	Technique for Human Error Rate Prediction
TGB	Turbine-Generator Building

TSP	Transfer Switch Panel
UAT	Unit Auxiliary Transformer
VCT	Volume Control Tank
VTT	Valtion Teknillinen Tutkimuskeskus (Technical Research Centre of Finland)
VVER	The Soviet (now Russian Federation) designation for light-water pressurized reactor
XLPE	Cross-Linked Polyethylene
ZOI	Zone of Influence

1
INTRODUCTION AND BACKGROUND

The U.S. Nuclear Regulatory Commission (NRC) approved the risk-informed and performance-based alternative regulation in Title 10 of the *Code of Federal Regulations* (10 CFR) 50.48(c) in July 2004, which allows licensees the option of using fire protection requirements contained in the National Fire Protection Association (NFPA) Standard 805, "Performance-Based Standard for Fire Protection for Light-Water Reactor Electric Generating Plants, 2001 Edition," with certain exceptions. To support licensees' use of that option, the NRC's Office of Nuclear Regulatory Research (RES) and the Electric Power Research Institute (EPRI) jointly issued NUREG/CR-6850 (EPRI 1011989), "Fire PRA Methodology for Nuclear Power Facilities," in September 2005. That report documents state-of-the art methods, tools, and data for conducting a fire probabilistic risk assessment (PRA) in a commercial nuclear power plant (NPP) application. This report is intended to serve the needs of a fire risk analysis team by providing a general framework for conducting the overall analysis, as well as specific recommended practices to address each key aspect of the analysis. Participants from the U.S. nuclear power industry supported demonstration analyses and provided peer review of the program. Methodological issues raised in past fire risk analyses, including the Individual Plant Examination of External Events (IPEEE), are addressed to the extent allowed by the current state-of-the-art and the overall project scope. Although the primary objective of the report is to consolidate existing state-of-the-art methods, in many areas, the newly documented methods represent a significant advance over previous methods.

NUREG/CR-6850 does not constitute regulatory requirements, and the NRC's participation in the study neither constitutes nor implies regulatory approval of applications based on the analysis contained in that document. The analyses and methods documented in that report represent the combined efforts of individuals from RES and EPRI. Both organizations provided specialists in the use of fire PRA to support this work. However, the results from that combined effort do not constitute either a regulatory position or regulatory guidance.

In addition, NUREG/CR-6850 can be used for risk-informed, performance-based approaches and insights to support fire protection regulatory decision making in general.

However, it is not sufficient to merely develop a potentially useful method, such as NUREG/CR- 6850, and announce its availability. It is also necessary to teach potential users how to properly use the method. To meet this need RES and EPRI have collaboratively conducted the NRC-RES/EPRI Fire PRA Workshops to train interested parties in the application of this methodology since 2005. The course is provided in five parallel modules covering tasks from NUREG/CR-6850 Reference [1].

These five training modules are:

- Module 1: PRA/Systems Analysis – This module covers the technical tasks for development of the system response to a fire including human failure events. Specifically, this module covers Tasks/Sections 2, 4, 5, 7, 14, and 15 of Reference [1].

- Module 2: Electrical Analysis – This module covers the technical tasks for analysis of electrical failures as the result of a fire. Specifically, this module covers Tasks/Sections 3, 9, and 10 of Reference [1].

- Module 3: Fire Analysis – This module covers technical tasks involved in development of fire scenarios from initiation to target (e.g., cable) impact. Specifically, this module covers Tasks/Sections 1, 6, 8, 11, and 13 of Reference [1].

- Module 4: Fire Human Reliability Analysis – This module covers the technical tasks associated with identifying and analyzing operator actions and performance during a postulated fire scenario. Specifically, this module covers Task 12 as outlined in Reference [1] based on the application of the approaches documented in Reference [2].

- Module 5: Advanced Fire Modeling – This module was added to the training in 2011. It covers the fundamentals of fire science and provides practical implementation guidance for the application of fire modeling in support of a fire PRA. Module 5 covers fire modeling applications for Tasks 8 and 11 as outlined in Reference [1] based on the material presented in Reference [3].

The first three modules are based directly on the "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," EPRI 1011989, and NUREG/CR-6850 [1]. However, that document did not cover fire human reliability analysis (HRA) methods in detail. In 2010, the training materials were enhanced to include a fourth module based on a more recent EPRI/RES collaboration and the then draft guidance document, EPRI 1019196, NUREG-1921 [2] published in late 2009. The training materials are based on this draft document including the consideration of public comments received on the draft report and the team's responses to those comments. In 2011 a fifth training module on Advanced Fire Modeling techniques and concepts was added to the course. This module is based on another joint RES/EPRI collaboration and a draft guidance published in January 2010, NUREG-1934 EPRI 1019195 [3].

In 2012 an additional first day of training was included in the NRC-RES/EPRI Fire PRA Workshop to cover principal elements of each technical area covered in the Fire PRA course, i.e., PRA, HRA, Electrical Analysis, and Fire Analysis. This introductory module was intended to assist in preparing the students to understand the in-depth fire PRA training modules that followed. The introductory modules were not intended to be a substitute for education and/or training in the subject matter. The intent was that they would serve as a primer for those individuals who lacked such training or those who were cross-training in an area other than their primary area of expertise.

The four introductory modules listed below (referred to as Module 0) were offered in parallel on the first day of the workshop.

Module 0a: Principles of PRA
Module 0b: Principles of Electrical Analysis

Module 0c: Principles of Fire Science and Modeling
Module 0d: Principles of HRA

These sub-modules are included in the text and on the accompanying DVDs as a part of their related module.

1.1. About this text

"Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) – 2012", is a collection of the materials that were presented at the two sessions of the NRC-RES/EPRI Fire PRA conducted July 16–20, 2012, and September 24-28, 2012.

The 2012 workshop was video recorded and adapted as an alternative training method for those who were unable to physically attend the training sessions. This NUREG/CP is comprised of the materials supporting those videos and includes the five volumes below (the videos are enclosed on DVD in the published paper copies of this NUREG/CP). This material can also serve as a refresher for those who attended one or more of the training sessions, and would be useful preparatory material for those planning to attend a session.

MARIAFIRES is comprised of 5 volumes.

Volume 1 – Module 0a Principles of PRA and Module 1: PRA/Systems Analysis
Volume 2 – Module 0b Principles of Electrical Analysis and Module 2: Electrical Analysis
Volume 3 – Module 0c Principles of Fire Science and Modeling and Module 3: Fire Analysis
Volume 4 – Module 0d Principles of HRA and Module 4: Fire Human Reliability Analysis
Volume 5 – Module 5: Advanced Fire Modeling

Integral to Modules 1, 2 and 3 is a set of hands-on problems based on a conceptual generic nuclear power plant (NPP) developed for training purposes. This generic plant is referred to in this text and in classroom examples as SNPP (Simplified Nuclear Power Plant). The same generic NPP is used in all three modules. Chapter 2 of this document provides the background information for the problem sets of each module, including a general description of the sample power plant and the internal events PRA needed as input to the fire PRA. The generic NPP defined for this training is an extremely simplified one that in many cases does not meet any regulatory requirements or good engineering practices. For training purposes, the design features presented highlight the various aspects of the fire PRA methodology.

For Module 4 and 5, independent sets of examples are used to illustrate key points of the analysis procedures. The examples for these two modules are not tied to the simplified plant. Module 4 uses examples that were derived largely from pilot applications of the proposed fire HRA methods and on independent work of the EPRI and RES HRA teams. The examples for Module 5 were taken directly from Reference [3] and represent a range of typical NPP fire scenarios across a range of complexity and that highlight some of the computation challenges associated with the NPP fire PRA fire modeling applications.

A short description of the Fire PRA technical tasks is provided below. For further details, refer to the individual task descriptions in EPRI 1011989, NUREG/CR-6850, Volume 2. The figure presented at the end of this chapter provides a simplified flow chart for the analysis process and indicates which training module covers each of the analysis tasks.

Plant Boundary Definition and Partitioning (Task 1). The first step in applying the fire PRA methodology is to define the physical boundary of the analysis and to divide the area within that boundary into analysis compartments.

Fire PRA Component Selection (Task 2). The selection of components that are to be credited for plant shutdown following a fire is a critical step in any fire PRA. Components selected would generally include many, but not necessarily all, components credited in the 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating prior to January 1, 1979," post-fire safe shutdown (SSD) analysis. Additional components will likely be selected, potentially including most, but not all, components credited in the plant's internal events PRA. Also, the proposed methodology would likely introduce components beyond either the 10 CFR 50 Appendix R list or the internal events PRA model. Such components are often of interest because of concern for multiple spurious actuations that may threaten the credited functions and components, as well as from concerns about fire effects on instrumentation used by the plant crew to respond to the event.

Fire PRA Cable Selection (Task 3). This task provides instructions and technical considerations associated with identifying cables supporting those components selected in Task 2 above. In previous fire PRA methods (such as EPRI Fire-Induced Vulnerability Evaluation (FIVE) and Fire PRA Implementation Guide), this task was relegated to the SSD analysis and its associated databases. NUREG/CR-6850 (EPRI 1011989) offers a more structured set of rules for selection of cables.

Qualitative Screening (Task 4). This task identifies fire analysis compartments that can be shown, without quantitative analysis, to have little or no risk significance. Fire compartments may be screened out if they contain no components or cables identified in Tasks 2 and 3 and if they cannot lead to a plant trip because of either plant procedures, an automatic trip signal, or technical specification requirements.

Plant Fire-Induced Risk Model (Task 5). This task discusses steps for the development of a logic model that reflects plant response following a fire. Specific instructions have been provided for treatment of fire-specific procedures or plans. These procedures may impact availability of functions and components or include fire-specific operator actions (e.g., self- induced station blackout).

Fire Ignition Frequency (Task 6). This task describes the approach to develop frequency estimates for fire compartments and scenarios. Significant changes from the EPRI FIVE method have been made in this task. The changes generally relate to the use of challenging events, considerations associated with data quality, and increased use of a fully component-based ignition frequency model (as opposed to the location/component-based model used, for example, in FIVE).

Quantitative Screening (Task 7). A fire PRA allows the screening of fire compartments and scenarios based on their contribution to fire risk. This approach considers the cumulative risk associated with the screened compartments (i.e., the ones not retained for detailed analysis) to ensure that a true estimate of fire risk profile (as opposed to vulnerability) is obtained.

Scoping Fire Modeling (Task 8). This step provides simple rules to define and screen fire ignition sources (and therefore fire scenarios) in an unscreened fire compartment.

Detailed Circuit Failure Analysis (Task 9). This task provides an approach and technical considerations for identifying how the failure of specific cables will impact the components included in the fire PRA SSD plant response model.

Circuit Failure Mode Likelihood Analysis (Task 10). This task considers the relative likelihood of various circuit failure modes. This added level of resolution may be a desired option for those fire scenarios that are significant contributors to the risk. The methodology provided in NUREG/CR-6850 (EPRI 1011989) benefits from the knowledge gained from the tests performed in response to the circuit failure issue.

Detailed Fire Modeling (Task 11). This task describes the method to examine the consequences of a fire. This includes consideration of scenarios involving single compartments, multiple fire compartments, and the main control room. Factors considered include initial fire characteristics; fire growth in a fire compartment or across fire compartments; detection and suppression; electrical raceway fire barrier systems, and damage from heat and smoke. Special consideration is given to turbine generator (T/G) fires, hydrogen fires, high-energy arcing faults (HEAF), cable fires, and main control board (MCB) fires. Considerable improvements can be found in the method for this task over the EPRI FIVE and Fire PRA Implementation Guide in nearly all technical areas.

Post-Fire Human Reliability Analysis (Task 12). This task considers operator actions for manipulation of plant components. The analysis task procedure provides structured instructions for identification and inclusion of these actions in the fire PRA. The procedure also provides instructions for estimating screening human error probabilities (HEPs) before detailed fire modeling results (e.g., fire growth and damage behaviors) have necessarily been developed or detailed circuit analyses (e.g., can the circuit spuriously actuate as opposed to simply assuming it can actuate) have been completed. In a fire PRA, the estimation of HEP values with high confidence is critical to the effectiveness of screening. This report does not develop a detailed fire HRA methodology. A number of HRA methods can be adopted for fire with appropriate additional instructions that superimpose fire effects on any of the existing HRA methods such as the Technique for Human Error Rate Prediction (THERP), Causal Based Decision Tree (CBDT), A Technique for Human Event Analysis (ATHEANA), etc. This would improve consistency across analyses (i.e., fire and internal events PRA).

Seismic Fire Interactions (Task 13). This task is a qualitative approach to help identify the risk from any potential interactions between an earthquake and a fire.

Fire Risk Quantification (Task 14). The task summarizes what is to be done for quantification of the fire risk results.

Uncertainty and Sensitivity Analyses (Task 15). This task describes the approach to follow for identifying and treating uncertainties throughout the fire PRA process. The treatment may vary from quantitative estimation and propagation of uncertainties where possible (e.g., in fire frequency and non-suppression probability) to identification of sources without quantitative estimation. The treatment may also include one-at-a-time variation of individual parameter values or modeling approaches to determine the effect on the overall fire risk (i.e., sensitivity analysis).

Fire PRA Documentation (Task 16). This task describes the approach to follow for documenting the Fire PRA process and its results. Figure 1 shows the relationship between the above 16 technical tasks from EPRI 1011989, NUREG/CR-6850, Volume 2.

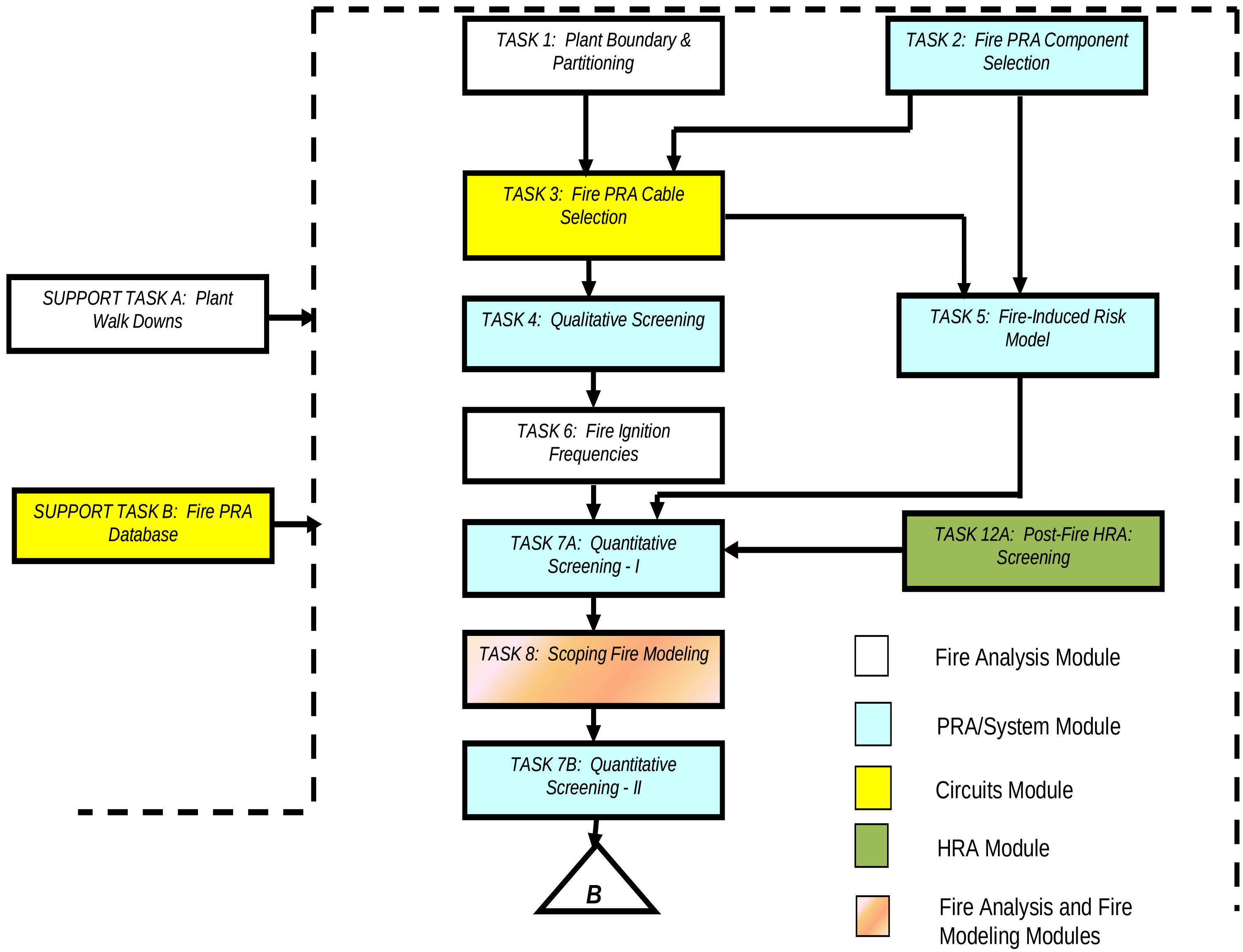


Figure 1-1 Relationship of Technical Tasks in NUREG/CR 6850 Volume 2

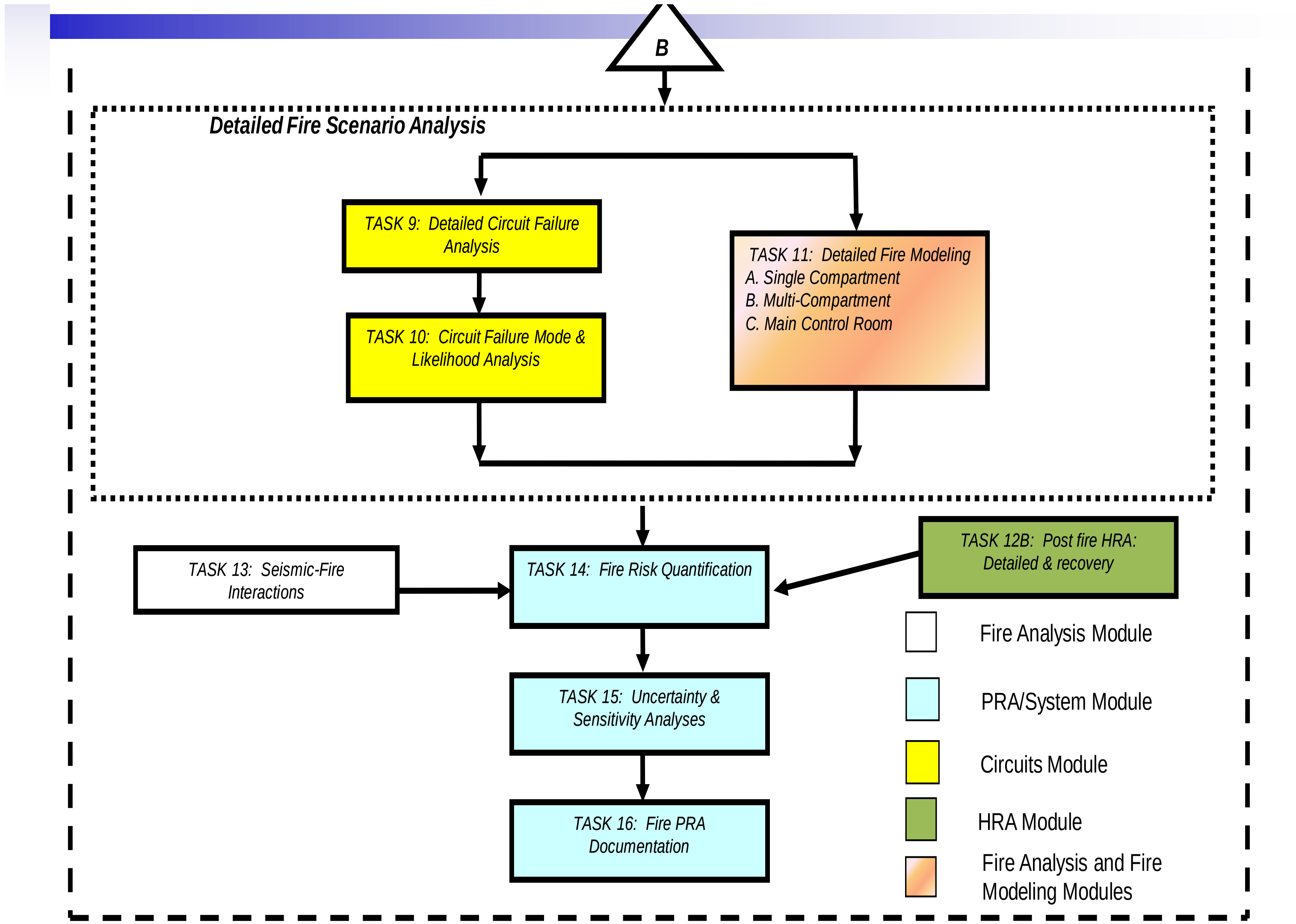


Figure 1-2 Note: "B" is from Task 7B (Previous Page)

1.2. References

1. NUREG/CR-6850, EPRI 1011989, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*, September 2005.

2. NUREG-1921, EPRI 1023001, *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines*, May 2012.

3. NUREG-1934, EPRI 1023259, *Nuclear Power Plant Fire Modeling Application Guide,* November 2012[1].

[1] At the time of the 2012 NRC-RES/EPRI Fire PRA Workshop, this final report had not yet been published. A draft for public comment was used to conduct the training.

2

PRINCIPLES OF HRA

The slides that follow were presented on the first day of the NRC-RES/EPRI Fire PRA Workshop during the extra day of training dedicated to presenting the fundamentals of the various subject areas to be covered during the remainder of the week.

2.1. Principles of Human Reliability Analysis (HRA)

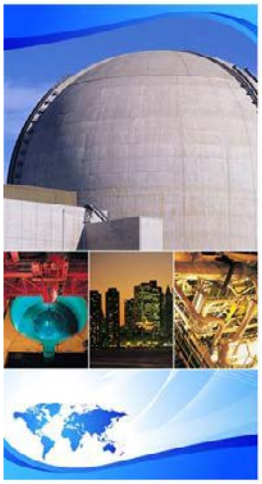
U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

CURTISS WRIGHT Flow Control Company SCIENTECH

SAIC Science Applications International Corporation



Principles of Human Reliability Analysis (HRA)

Joint NRC-RES/EPRI Fire PRA Workshop 2012
Bethesda, MD

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Course Objectives

- Introduce Human Reliability Analysis (HRA), in the context of PRA for nuclear power plants.
- Provide students with a basic understanding of HRA:
  - What is HRA?
  - Where does HRA fit into PRA?
  - What does HRA model?
  - Is there a standard for performing HRA?
  - What guidance is there for performing HRA?
  - What are the keys to performing HRA?
  - How can we understand human error?
  - What are the important features of existing HRA methods?
  - What are the HRA concerns or issues for fire PRA?

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 2

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Course Outline

- **What is HRA?**
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

Human Reliability Analysis (HRA) ….

Is generally defined as:

- A **structured approach** used to **identify** potential human failure events (HFEs) and to systematically **estimate the probability** of those errors using data, models, or expert judgment

Is developed because:

- **PRA reflects the as-built, as-operated plant**
- **HRA is needed to model the "as-operated" portion (and cross-cuts many PRA tasks and products)**

Produces:

- Identified and defined human failure events (HFEs)
- Qualitative evaluation of factors influencing human errors and successes
- Human error probabilities (HEPs) for each HFE

HRA …. (continued)

- Requires inputs from many technical disciplines, e.g.,:
  - PRA
  - Plant design and behavior
  - Engineering (e.g., thermal hydraulics)
  - Plant operations
  - Procedures and how they are used
  - Ergonomics of monitoring and control interfaces (both inside and outside control room)
  - Cognitive and behavioral science
  - Etc., etc., etc.
- Is performed by:
  - A multi-disciplinary team

Course Outline

- What is HRA?
- **Where does HRA fit into PRA?**
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

Overview of PRA Process

- PRAs are performed to find severe accident weaknesses and provide quantitative results to support decision-making. Three levels of PRA have evolved:

Level	An Assessment of:	Result
1	Plant accident initiators and systems'/operators' response	Core damage frequency and contributors
2	Reactor core melt, and frequency and modes of containment failure	Categorization and frequencies of containment releases
3	Public health consequences	Estimation of public and economic risks

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 7

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

PRA Classification

- Internal Hazards – risk from accidents initiated internal to the plant
  - Includes internal events, internal flooding and internal fire events
- External Hazards – risk from external events
  - Includes seismic, external flooding, high winds and tornadoes, airplane crashes, lightning, hurricanes, etc.
- At-Power – accidents initiated while plant is critical and producing power (operating at >X%* power)
- Low Power and Shutdown (LP/SD) – accidents initiated while plant is <X%* power or shutdown
  - Shutdown includes hot and cold shutdown, mid-loop operations, refueling

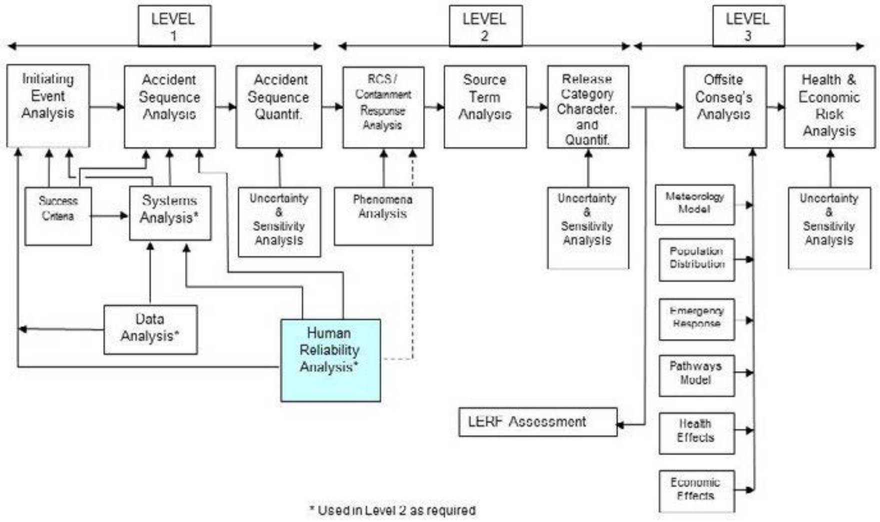
**X is usually plant-specific. The separation between full and low power is determined by evolutions during increases and decreases in power.*

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 8

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Principal Steps in PRA



Principal Steps in PRA (continued)

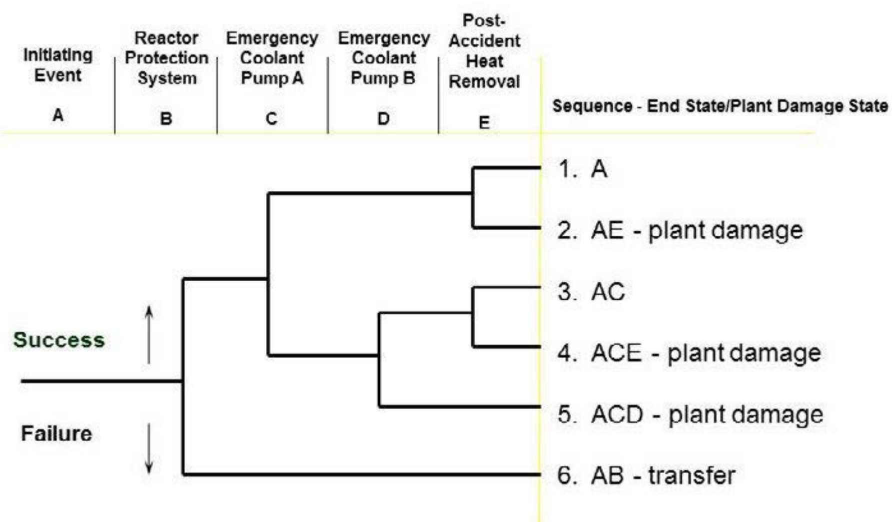
- First, we'll look at how HRA fits into Event Tree (ETs) models.

Human Events in Event Trees

Nature of event trees (and where HRA fits in):

- Typically used to model the response to an initiating event
- Features:
  - Generally, a unique system-level event tree is developed for each initiating event group
  - Identifies systems/functions required for mitigation
  - Identifies operator actions required for mitigation
  - Identifies event sequence progression
  - End-to-end traceability of accident sequences leading to bad outcome
- Primary use
  - Identification of accident sequences which result in some outcome of interest (usually core damage and/or containment failure)
  - Basis for accident sequence quantification

Simple Event Tree



System-Level Event Tree Development

- A system-level event tree consists of an initiating event (one per tree), followed by a number of headings (top events), and sequences of events defined by success or failure of the top events
- Top events represent the systems, components, and/or human actions required to mitigate the initiating event
- To the extent possible, top events are ordered in the time-related sequence in which they would occur
  - Selection of top events and ordering reflect emergency procedures
- Each node (or branch point) below a top event represents the success or failure of the respective top event
  - Logic is typically binary
    - Downward branch – failure of top event
    - Upward branch – success of top event
  - Logic can have more than two branches, with each branch representing a specific status of the top event

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 13

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

System-Level Event Tree Development (continued)

- Dependencies among systems (to prevent core damage) are identified
  - Support systems can be included as top events to account for significant dependencies (e.g., diesel generator failure in station blackout event tree)
- Timing of important events (e.g., physical conditions leading to system failure) determined from thermal-hydraulic (T-H) calculations
- Branches can be pruned logically to remove unnecessary combinations of system successes and failures
  - This minimizes the total number of sequences that will be generated and eliminates illogical sequences
- Branches can transfer to other event trees for development
- Each path of an event tree represents a potential scenario
- Each potential scenario results in either prevention of core damage or onset of core damage (or a particular end state of interest)

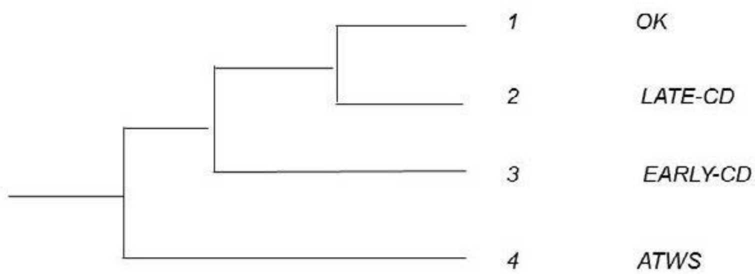
Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 14

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Functional Event Tree

Initiating Event	Reactor Trip	Short term core cooling	Long term core cooling	SEQ #	STATE
IE	RX-TR	ST-CC	LT-CC		



Critical Safety Functions

Example safety functions for core and containment

- Reactor subcriticality
- Reactor coolant system overpressure protection
- Early core heat removal
- Late core heat removal
- Containment pressure suppression
- Containment heat removal
- Containment integrity

Example BWR Mitigating Systems

Function	Systems
Reactivity Control	Reactor Protection System, Standby Liquid Control, Alternate Rod Insertion
RCS Overpressure Protection	Safety/Relief Valves
Coolant Injection	High Pressure Coolant Injection, High Pressure Core Spray, Reactor Core Isolation Cooling, Low Pressure Core Spray, Low Pressure Coolant Injection (RHR) Alternate Systems- Control Rod Drive Hydraulic System, Condensate, Service Water, Firewater
Decay Heat Removal	Power Conversion System, Residual Heat Removal (RHR) modes (Shutdown Cooling, Containment Spray, Suppression Pool Cooling)

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 17

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example PWR Mitigating Systems

Function	Systems
Reactivity Control	Reactor Protection System (RPS)
RCS Overpressure Protection	Safety valves, pressurizer Power-Operated Relief Valves (PORVs)
Coolant Injection	Accumulators, High Pressure Safety Injection (HPSI), Chemical Volume and Control System (CVCS), Low Pressure Safety Injection (LPSI), High Pressure Recirculation (may require LPSI)
Decay Heat Removal	Power Conversion System, Auxiliary Feedwater (AFW), Residual Heat Removal (RHR), Feed and Bleed (PORV + HPSI)

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 18

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

System Success Criteria

- Identify systems which can perform each function
- Often include if the system is automatically or manually actuated.
- Identify minimum complement of equipment necessary to perform function (often based on thermal/hydraulic calculations, source of uncertainty)
  - Calculations often realistic, rather than conservative
- May credit non-safety-related equipment where feasible

Example Success Criteria

IE	*Reactor Trip*	*Short Term Core Cooling*	*Long Term Core Cooling*
Transient	*Auto Rx Trip or Manual Rx Trip*	*Power Conversion System or 1 of 3 AFW or 1 of 2 PORVs and 1 of 2 ECI*	*Power Conversion System or 1 of 3 AFW or 1 of 2 PORVs and 1 of 2 ECR*
Medium or Large LOCA	*Auto Rx Trip or Manual Rx Trip*	*1 of 2 ECI*	*1 of 2 ECR*

What does HRA do with ET information?

For example, the HRA analyst:

- From initiating event and subsequent top events on ET:
  - Identifies the procedures and procedure path that lead to successful mitigation of the initiating event
- From success criteria:
  - Determines what defines an operator failure (e.g., fewer pumps started than needed, actions performed too late in time)
- From plant behavior timing provided by T-H calculations:
  - Determines what plant parameters, alarms, and other indications are available to help operators:
    - understand the plant state (initially and as the accident progresses)
    - use procedures appropriately to respond to specific accident sequence
- Any plant function-related human failure events (HFEs) can be defined.

What does HRA do with ET information? (continued)

- From the various branches on the event tree (combined with success criteria and timing information):
  - Identifies (or confirms) what operator actions, if failed, could result in "down" branches and certain plant damage states (alone or in combination with system failures) (i.e., define an HFE)
  - Identifies what specific operator actions (e.g., fails to start HPI Train A pump, turns off Safety Injection) would result in a "down" branch (i.e., define an HFE)
  - Identifies what procedure paths might be plausibly taken that would result in operator failures
  - Identifies what plant information (or missing information) might cause operators to take inappropriate procedure paths
- These inputs also can be as factors influencing the selection of screening values for human failure events.

Principal Steps in PRA (continued)

- Next, we'll see how HRA is included in Fault Tree (FT) models.

Human Events in Fault Trees

Characteristics of fault trees (and where HRA fits in):

- Deductive analysis (event trees are inductive)
- Start with undesired event definition
- Used to estimate system failure probability
- Explicitly model multiple failures
- Identify ways by which a system can fail
- Models can be used to find:
  - System "weaknesses"
  - System failure probability
  - Interrelationships between fault events

Human Events in Fault Trees (continued)

- Fault trees are graphic models depicting the various paths of combinations of faults that will result in the occurrence of the undesired top event.
- Fault tree development moves from the top event to the basic event (or faults) which can cause it.
- Fault tree consists of gates to develop the fault logic in the tree.
- Different types of gates are used to show the relationship of the input events to the higher output event.
- Fault tree analysis requires thorough knowledge of how the system operates and is maintained.

Specific Failure Modes Modeled for Each Component

- Each component associated with a specific set of failure modes/mechanisms determined by:
  - Type of component (e.g., motor-driven pump, air-operated valve)
  - Normal/Standby state
    - Normally not running (standby), normally open
  - Failed/Safe state
    - Failed if not running, or success requires valve to stay open

Typical Component Failure Modes

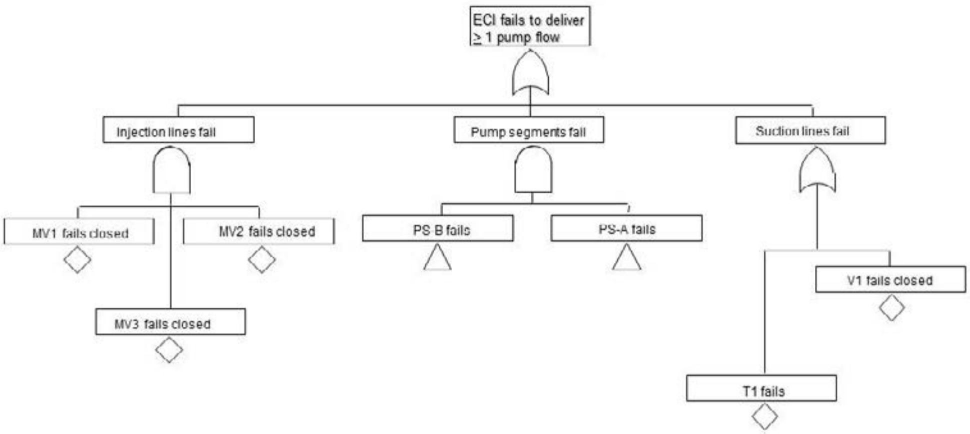
- Active Components
  - Fail to Start*
  - Fail to Run*
  - Fail to Open/Close/Operate*
- Additional "failure mode" is component is unavailable because it is out for test or maintenance

* In addition to hardware failures that have these failure modes, an operator "error of commission" (that suppresses actuation or operation, or turns off equipment) also can cause these failure modes.

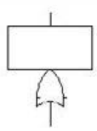
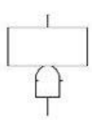
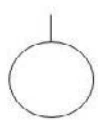
Active Components Require "Support"

- Signal needed to "actuate" component
  - Safety Injection Signal starts pump or opens valve
- If system is a "standby" system, operator action may be needed to actuate (and failure to actuate is modeled as an HFE)
- Support systems might be required for component to function
  - AC and/or DC power
  - Service water or component water cooling
  - Room cooling

Simplified Fault Tree for Failure of Emergency Coolant Injection (ECI)



Fault Tree Symbols

Symbol		Description
	"OR" Gate	Logic gate providing a representation of the Boolean union of input events. The output will occur if at least one of the inputs occur.
	"AND" Gate	Logic gate providing a representation of the Boolean intersection of input events. The output will occur if all of the inputs occur.
	Basic Event	A basic component fault which requires no further development. Consistent with level of resolution in databases of component faults.

What does HRA do with FT information?

- From the top events and types of equipment modeled in the fault tree:
  - Identify and define any human failure events (HFEs) that could result in system, train, or component failures (e.g., starting, actuating, opening/closing)
- From review of procedures and other documents related to testing and maintenance:
  - Identify and define operator failures to restore systems, trains, or components following testing or maintenance
  - Determine the frequency of testing and preventive maintenance
  - Determine what post-testing and post-maintenance checks are performed
- These inputs also can be used in selecting appropriate screening values for HFEs.

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- **What does HRA model?**
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

Human Reliability Analysis

- Starts with the basic premise that the humans can be represented as either:
  - A component of a system, or
  - A failure mode of a system or component.
- Identifies and quantifies the ways in which human actions initiate, propagate, or terminate accident sequences.
- Human actions with both positive and negative impacts are considered in striving for realism.
- A difficult task in a PRA since the HRA analyst needs to understand the plant hardware response, the operator response, the accident progression modeled in the PRA.
- Not everything the operator does is modeled in the PRA!

Human Reliability Analysis Objectives

Ensure that the **impacts of plant personnel** actions are reflected in the assessment of risk in such a way that:

a) both **pre-initiating event and post-initiating event** activities, including those modeled in support system initiating event fault trees, are addressed.

b) logic model elements are defined to represent the effect of such personnel actions on **system availability**/unavailability and on **accident sequence** development.

c) plant-specific and scenario-specific factors are accounted for, including those factors that influence either what activities are of interest or human performance.

d) human performance issues are addressed in an integral way so that **issues of dependency are captured**.

Ref. ASME RA-Sa-2009

Categories of Human Failure Events in PRA

- Operator actions can occur throughout the accident sequence:
  - Before the initiating event (i.e., pre-initiator)
  - As a cause of the initiating event
  - After the initiating event (i.e., post-initiator)

Categories of Human Failure Events: Pre-Initiator HFEs

- Sometimes called "latent errors" because they are not revealed until there is a demand for the affected system (after the initiating event).
- Examples:
  - Failure to restore valve lineup following routine system testing
  - Failure to rack-in pump breaker in following preventive maintenance
  - Mis-calibration of instruments
- Most frequently relevant outside main control room
- Some of these failures are captured in equipment failure data.
- For HRA, the focus is on equipment being left misaligned, unavailable, or not working exactly right (accounting for post-test/post-maintenance verification).

Categories of Human Failure Events: Initiating-Event Related

- Operator actions can contribute to the occurrence of or **cause initiating events** (i.e., human-induced initiators)
- In PRAs, such events are most often
  - Included implicitly in the data used to quantify initiating event frequencies, and
  - Therefore not modeled explicitly in the PRA
- Operator actions can be particularly relevant for operating conditions other than power operation
  - Human-caused initiating events can have unique effects (e.g., causing drain-down of reactor or RCS during shutdown)
  - Actions that cause initiating events may also have implications for subsequent human response (i.e., dependence can be important)

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 37

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Categories Of Human Failure Events: Post-Initiator HFEs

- **Post-initiator HFEs** account for failures associated with response to an initiating event
- Typically reflect failure to take necessary action (in main control room or locally)
  - Failure to initiate function of manually-actuated system
  - Failure to back up an automatic action
  - Failure to recover from other system failures
    - Reconfigure system to overcome failures (e.g., align electrical bus to alternative feed)
    - Make use of an alternative system (e.g., align fire water to provide pump cooling)
- Most often reflect failure to take actions called for by procedures

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 38

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Other Classifications of Human Failure Events

- Another way to classify human failure events (HFEs) from the perspective of the PRA is:
  - Error of omission (EOO)
  - Error of commission (EOC)
- Errors of omission (EOOs):
  - *A human failure event resulting from a failure to take a required action, leading to an unchanged or inappropriately changed and degraded plant state.*
  - Examples:
    - Failure to start auxiliary feedwater system
    - Failure to block automatic depressurization system signals

Other Classifications of HFEs (continued)

- Errors of commission (EOCs):
  - *A human failure event resulting from a well-intended but inappropriate, overt action that, when taken, leads to a change in the plant and results in a degraded plant state.*
  - Often, these events represent "good" operating practice, but applied to the wrong situation (especially, when understanding the situation is difficult).
  - Examples:
    - Prematurely terminating safety injection (because operators think SI is not needed; but for the specific situation, SI is needed).

Other Classifications of HFEs (continued)

- Pre-initiator HFEs can be either EOOs or EOCs:
  - These HFEs usually represent failures in execution (i.e., failures to accomplish the critical steps; these steps are typically already decided so no decision-making is required).
  - Execution failures are often caused by inattention (or over-attention) failures
  - Examples:
    - Inattention: Skipped steps (especially, following interruptions or other distractions)
    - Over-attention: Repeated or reversed steps

Other Classifications of HFEs (continued)

- Most post-initiator HFEs that are modeled are EOOs:
  - These HFEs can represent either failures in execution or cognitive failures (such as failures in diagnosis of the plant condition or decision-making regarding procedure use for a particular situation).
  - Most PRAs ***only include*** EOOs; however, EOCs have been involved in many significant accidents, both in nuclear power industry and others.
  - Later, we'll see that the fire PRA methodology for NFPA-805 requires that certain EOCs be addressed.

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- **Is there a standard for performing HRA?**
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 43

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Standard for HRA?

- NRC's Regulatory Guide 1.200 provides staff position for one approach in determining the technical adequacy of a PRA to support a risk-informed activity
- The staff position, in determining technical adequacy, defines a technically acceptable base PRA
- For each technical element (e.g., HRA)
  - Defines the necessary attributes and characteristics of at technically acceptable HRFA
  - Allows use of a standard in conjunction with a peer review to demonstrate conformance with staff position
  - Endorses ASME/ANS standard and NEI peer review guidance (with some exceptions)

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 44

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Standard for HRA? (continued)

- RG 1.200 specifies what is needed in a technically acceptable PRA/HRA
- ASME/ANS PRA standard defines requirements*
  - Specifies **what** you need to do.
- These standard requirements have been established to ensure PRA quality commensurate with the type of PRA application and/or regulatory decision

*The use of the word "Requirements" is Standard language and is not meant to imply any regulatory requirement

Standard for HRA? (continued)

- The standard provides two levels of technical requirements:
  - High level requirements (HLRs)
  - Supporting requirements (SRs)
- The HLRs provide the minimum requirements for a technically acceptable baseline PRA. The HLRs are defined in general terms and reflect the diversity of approaches and accommodate future technological innovations.
- The SRs define the requirements needed to accomplish each HLR

Standard for HRA? (continued)

- In defining the SRs, the standard recognizes that, depending on the application, the level of detail, the level of plant specificity and the level of realism can vary
- Three capability categories are defined, and the degree to which each is met increases from Category I to Category III
- Each SR is defined to a different "Capability Category"
- Within a PRA, even the HRA element can be a mixture of capability categories.

Standard for HRA? (continued)

- Capability Category I:
  - Scope and level of detail are sufficient to identify relative importance of contributors down to system or train level.
  - Generic data and models are sufficient except when unique design or operational features need to be addressed.
  - Departures from realism have moderate impact on results.
- Capability Category II:
  - Scope and level of detail are sufficient to identify relative importance of significant contributors down to component level, including human actions.
  - Plant-specific data and models are used for significant contributors.
  - Departures from realism have small impact on results.

Standard for HRA? (continued)

- Capability Category III:
  - Scope and level of detail are sufficient to identify relative importance of contributors down to component level, including human actions.
  - Plant-specific data and models are used for all contributors.
  - Departures from realism have negligible impact on results.

Objective HRA Technical Element in ASME/ANS PRA Standard

The objective of the human reliability element of the PRA is to ensure that the impacts of plant personnel actions are reflected in the assessment of risk in such a way that:

- Both pre-initiating event and post-initiating event activities addressed
- Logic model elements are defined to represent the effect of such personnel actions
- Plant-specific and scenario-specific factors are accounted for
- Human performance issues are addressed in an integral way so that issues of dependency are captured

PRA Standard Requirements for HRA

ASME HRA **High Level Requirements** Compared

Pre-Initiator	Post Initiator
A – Identify HFEs	E – Identify HFEs
B – Screen HFEs	
C – Define HFEs	F – Define HFEs
D – Assess HEPs	G – Assess HEPs
	H – Recovery HFEs
I – Document HFEs/HEPs	

ASME/ANS Standard Post-Initiator HRA High Level Requirements (HLRs)

- Examples of High Level Requirements (HLRs) for post-initiator HFEs:

HLR-HR-E

A systematic review of the relevant procedures shall be used to identify the set of operator responses required for each of the accident sequences

HLR-HR-F

Human failure events shall be defined that represent the impact of not properly performing the required responses, consistent with the structure and level of detail of the accident sequences.

ASME/ANS Standard Post-Initiator HRA High Level Requirements

- Examples (continued):

HLR-HR-G

The assessment of the probabilities of the post-initiator HFEs shall be performed using a well defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence.

HLR-HR-H

Recovery actions (at the cutset or scenario level) shall be modeled only if it has been demonstrated that the action is plausible and feasible for those scenarios to which they are applied. Estimates of probabilities of failure shall address dependency on prior human failures in the scenario

ASME/ANS Standard Pre- and Post-Initiator HRA High Level Requirements

- Examples (continued):

HLR-HR-I

The HRA shall be documented consistent with the applicable supporting requirements (HLR-HR-I).

ASME/ANS Standard Post-Initiator HRA Supporting Requirements (SRs)

- Examples of Supporting Requirements (SRs) for post-initiator HFEs:

HR-E1

When identifying the key human response actions review (a) the plant-specific emergency operating procedures, and other relevant procedures (e.g., AOPs, annunciator response procedures) in the context of the accident scenarios (b) system operation such that an understanding of how the system(s) and the human interfaces with the system is obtained. (All Capability Categories)

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 55

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

ASME/ANS Standard Post-Initiator HRA Supporting Requirements (SRs)

- Examples (continued):

HR-G1

Capability Category I: Use conservative estimates (e.g., screening values) for the HEPs of the HFEs in accident sequences that survive initial quantification.

Capability Category II: Perform detailed analyses for the estimation of HEPs for signification HFEs. Use screening values for HEPs for non-significant human failure basic events.

Capability Category III: Perform detailed analyses for the estimation of human failure basic events.

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 56

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

ASME/ANS Standard Post-Initiator HRA Supporting Requirements (SRs)

- Examples (continued):

HR-G6

Check the consistency of the post-initiator HEP quantifications. Review the HFEs and their final HEPs relative to each other to check their reasonableness given the scenario context, plant history, procedures, operational practices, and experience. (All Capability Categories)

ASME/ANS Standard: Supporting and Fire HRA-Specific Requirements

- The standard is for an at-power Level 1/LERF PRA for both internal and external hazards
- The requirements in the PRA standard for internal events provide the requirements for the base PRA model
- The other hazards (e.g., internal fires) build upon the base PRA model for internal events
- In general, the HRA requirements (both HLRs and SRs) for internal events apply to the other hazards (e.g., fire, seismic).
- The Fire HRA Track presented this week will identify HLRs and SRs specifically applicable in performing fire HRA/PRA.

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- **What guidance is there for performing HRA?**
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

HRA Guidance – How To….

- From our last presentation:
  - The standard specifies **what** you need to do.
  - Guidance, on the other hand, is a description of **how-to** do something…..
- In this presentation, we will discuss three different types of HRA guidance associated with:
  1. HRA processes
  2. Other HRA tools or approaches
  3. HRA quantification methods

HRA Processes

- An HRA process is a prescribed set of steps for **<u>how to</u>** perform an HRA.
- Usually, an HRA process explicitly identifies steps that are also products of HRA, i.e.,
  1. Identification and definition of human failure events (HFEs),
  2. Quantification of each HFE (i.e., assignment of human error probabilities (HEPs)),
  3. Qualitative analysis that supports #1 and #2, and
  4. Documentation of all of the above.

HRA Processes (continued)

- Not many HRA processes have been published.
- Usually, the HRA process provides both:
  1. Steps for **<u>how to</u>** perform HRA, and
  2. **<u>How to</u>** perform the steps.
- Two examples of published <u>stand-alone</u> HRA processes are:
  - EPRI's " SHARP1 – A Revised Systematic Human Action Reliability Procedure," EPRI TR-101711, December 1992
  - NRC's "Good Practices for Implementing Human Reliability analysis (HRA)," NUREG-1792, April 2005

* "Stand-alone" means that they are not connected with a specific HRA quantification method.

HRA Processes (continued)

- SHARP1:
  - Written to provide a "user-friendly tool" for utilities in preparing Individual Plant Examinations (IPEs) back in the early 1990s.
  - Written to enhance the original SHARP, developed in 1984, to:
    - Address review comments
    - Incorporate the experience and insight gained in intervening years
  - Described as a "framework…for incorporating human interactions into PRA…" with emphasis on the iterative nature of the process.
  - Structured in "stages" to provide additional guidance for systematically integrating HRA into the overall plant logic model of the PRA.
  - Describes and compares selected HRA methods for quantification.
  - Includes four case studies.

HRA Processes (continued)

- SHARP1 describes how to formulate a project team to perform HRA.
- SHARP1 is organized into four "stages" to define clearly the interactions with major PRA tasks:
  - Stage 1: Human Interaction Event Definition and Integration into Plant Logic Model
  - Stage 2: Human Interaction Event Quantification
  - Stage 3: Recovery Analysis
  - Stage 4: Internal Review
- The original seven steps in SHARP still apply (but are captured within these four stages).

HRA Processes (continued)

- SHARP1 uses three broad categories of human interactions:
  - Type A: Pre-initiating event interactions
  - Type B: Initiating event interactions
  - Type C: Post-initiating event interactions
    - CP: Actions dictated by operating procedures and modeled as essential parts of the plant logic model
    - CR: Recovery actions
- SHARP1 emphasizes the importance of dependencies between human interactions (especially with respect to premature screening of important interactions) and defines four classes of dependencies.

HRA Processes (continued)

- SHARP1 provides detailed guidance on **how to** define and place HFEs into the plant logic model, including:
  - example event trees and fault trees
  - comparisons of procedure steps with what an HFE represents
  - detailed accounts for four case studies
- SHARP1 provides some discussion of influence and/or performance shaping factors, but there is no particular emphasis on this topic.
- Qualitative HRA is not explicitly identified or discussed, but is incorporated into different "stages"

HRA Processes (continued)

- NRC's "Good Practices for HRA":
  - Written to establish "good practices" for performing HRA and to assess the quality of HRA, when it is reviewed.
  - Are generic in nature; not tied to any specific methods or tools.
  - Written to support implementation of RG 1.200 for Level 1 and limited Level 2 internal event, at-power PRAs (using direct links between elements of "good practices" and RG 1.200).
  - Consequently, written ultimately to address issues related to PRA quality and associated needs for confidence in PRA results used to support regulatory decision-making.
  - Developed using the experience of NRC staff and its contractors, including lessons learned from developing HRA methods, performing HRAs, and reviewing HRAs.

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 67

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

HRA Processes (continued)

- NRC's "Good Practices" (GPs) address the following:
  - HRA team formation and overall guidance (2 GPs), e.g.,
    - Should use a multidisciplinary team
    - Should perform field observations
  - Pre-initiator HFEs (15 GPs), e.g.,
    - In identifying HFEs, should review procedures for all routine testing and maintenance
    - In quantifying HFEs, it is acceptable to use screening values if: a) the HEPs are clearly overestimates and b) dependencies among multiple HFEs are conservatively accounted for.
    - In quantifying HFEs, should account for the most relevant plant- and activity-specific performance shaping factors (PSFs).

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 68

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

HRA Processes (continued)

- NRC's "Good Practices" (GPs) address (continued):
  - Post-initiator HFEs (17 GPs), e.g.,
    - In identifying HFEs, should review post-initiator related procedures and training.
    - In modeling (a.k.a., defining) HFEs, should define such that they are plant- and accident sequence-specific.
    - In quantifying HFEs, should address both diagnosis and response execution failures.
    - In adding recovery actions, should consider a number of aspects (e.g., whether cues will be clear and timely, whether there is sufficient time available, whether sufficient crew resources exist)
  - Errors of commission (2 GPs), e.g.,
    - Recommend to identify and model potentially important EOCs.

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 69

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

HRA Processes (continued)

- NRC's "Good Practices" (GPs) address (continued):
  - HRA documentation (1 GP), i.e.,
    - Should allow a knowledgeable reviewer to understand the analysis enough that it could be approximately reproduced and the same resulting conclusion reached.
- Does not explicitly address human-induced initiating events, but GPs for pre-initiator HFEs and post-initiator HFEs also should apply to HFEs that induce initiating events.

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 70

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

HRA Processes (continued)

- Neither SHARP1 nor NRC's "Good Practices" specify or dictate:
  - Which HRA method should be used to perform HRA quantification
  - Any specific HRA tools or approaches for performing HFE identification and definition, and qualitative analysis
- In fact, often an HRA method does not:
  - Provide an accompanying and explicit HRA process for applying that specific method, and/or
  - Specify which (or that any) HRA process (e.g., SHARP) should be used to apply the specific method.
- Consequently, it usually is up to the HRA analyst to decide on selecting and applying an explicit HRA process to follow.

HRA Processes (continued)

- However, there are a few HRA quantification methods that provide a specific HRA process.
- Examples of such methods:
  - THERP (NUREG/CR-1278)
  - ATHEANA (NUREG-1624, Rev. 1)
  - Fire HRA Guidelines (NUREG-1921/EPRI TR 1023001, to be published)
- For both ATHEANA and the Fire HRA Guidelines, the HRA process steps include explicit guidance for certain steps or use of HRA tools, such as:
  - Approaches for identifying HFEs (e.g., EOCs)
  - Approaches or techniques for doing certain aspects of qualitative HRA (e.g., determining if an operator action is feasible and, therefore, suitable to be included in PRA)

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- **What are the keys to performing HRA?**
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

What are the keys to performing HRA?

The key is to….

What are the keys to performing HRA?

…understand the problem.

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 75

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

What are the keys to performing HRA?

- Why do you need to "understand the problem"?
  1. To be able to identify, define, and model (i.e., place appropriately in the plant logic model) HFEs such that they are consistent with, for example:
     - the specific accident sequence
     - associated plant procedures and operations
     - expected plant behavior and indications
     - engineering calculations that support the requirements for successful accident mitigation
     - consequences that are risk-significant

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 76

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

What are the keys …? (continued)

- Why do you need to "understand the problem"? (continued)

2. To appropriately select an HRA quantification method to (usually) indirectly represent how operators are expected to behave, based on, for example:
    - their procedures and training
    - plant-specific (and maybe even crew-specific) styles for responding to accidents
    - plant-specific operating experience
    - general understanding of human error, behavior and cognitive science, human factors and ergonomics
    - knowledge of HRA methods and their underlying bases
3. To support and justify the HFEs and their quantification

What are the keys …? (continued)

- How do you develop this understanding?
    - Perform an appropriately thorough **qualitative analysis**, performed **iteratively** and **repeatedly** throughout the entire HRA process until the final HRA quantification is done.
- How do you know when are you done?
    - Usually, one or more of the following has occurred:
        - The accident sequence analyst tells you that you should move on to a new problem/HFE (that is more risk-significant).
        - Your deadline has arrived.
        - Your money is spent.

What are the keys …? (continued)

- Increasingly, the HRA/PRA recognizes the importance of HRA qualitative analysis.
- More focus on qualitative analysis is appearing in recent or upcoming HRA/PRA guidance, e.g.,
  - Joint EPRI/NRC-RES Fire HRA guidance (NUREG-1921/EPRI TR 1023001, to be published)
  - ATHEANA (NUREG-1624, Rev. 1)
  - EPRI's HRA Calculator
- This emphasis is supported or based on recent studies such as:
  - "International HRA Empirical Study – Phase 1 Report" (NUREG/IA-0216, Volume 1, 2009)

What are the keys to performing HRA?

An important key to building an understanding of the problem is…

What are the keys to performing HRA?

context.

What are the keys to performing HRA?

- Context has long been recognized as important, e.g.,
  - SHARP1 (1992) discusses the importance of addressing human interactions for plant-specific and accident sequence-specific scenarios.
- However, a commonly held belief, still evident in popular accounts of incidents and reflected in how some people regard what new technologies ought to accomplish, is:
  - If we could just eliminate the human, we'd never have any problems.
- This corresponds with the so-called "blame culture" or "human-as-a-hazard" view

What are the keys …? (continued)

- Of course, the “human” here is the one on the “sharp end,” i.e., the last one to “touch” any equipment or try to respond to an accident.
- But, humans also are involved in design, planning, inspection, testing, manufacturing, software development, etc., etc., etc.

- Let’s look at some everyday examples of what humans on the “sharp end” have to contend with as a way of understanding the impact of “context” and how we may be “set up” for failure.

What are the keys to performing HRA?

What are the keys to performing HRA?

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 85

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

What are the keys to performing HRA?

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 86

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

What are the keys … HRA? (continued)

- Recent research on human error and human actions involved in <u>serious accidents</u> has contributed to building a new perspective on the role of humans in technology and the role of context.
- Examples of research/researchers include:
  - James Reason, *Human Error*, 1990, *Managing the Risks of Organizational Accidents*, 1997, *The Human Contribution: Unsafe Acts, Accidents and Heroic Recoveries*, 2008.
  - Donald R. Norman, *The Design of Everyday Things*, 1988.
  - E. M. Roth and R.J. Mumaw, *An Empirical Investigation of Operator Performance in Cognitively Demanding Simulated Emergencies*, NUREG/CR-6208, 1994.
  - Others, such as: Eric Hollnagel, David Woods, Micah Endsley

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 87

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

What are the keys …? (continued)

- Some of the key messages from this body of research are:
  - The operator is often "set-up" for failure …
    - …by prior events, pre-existing conditions, failed or misleading information, unusual and unfamiliar plant conditions and configurations, procedures that don't match the situation, and so on.
  - But, he doesn't always fail…
    - …"[E]ven the best [trouble-shooters] have bad days. It is my impression that the very best trouble-shooters get it right about half the time. The rest of us do much worse." (Reason, *The Human Contribution*, page 66)
  - So, he's the "last line of defense" …
    - …after all other previous designs and plans have failed.

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 88

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

What are the keys …? (continued)

Suggestions for some practical exercises on context

1. You want a book off the shelf in your living room. You even go to the living room to get the book. However, after you return to your home office, you discover that you never got the book.
2. You have a doctor's appointment. Despite reminding yourself of the location for the doctor's office while you drive away from home, you end up at your children's school instead.
3. You drive yourself to work every day on the same route, you have a good driving record, and you drive defensively. Somehow, you end up in a collision with another vehicle.

All unlikely, right? Now, think about how the context might "cause" you to make one of these mistakes.

What are the keys …? (continued)

Suggestions for some practical exercises on context

1. In Reason's *Human Error*, the context was an interruption, namely knocking a bunch of books off the shelf. After picking up all the books, you forget why you were there in the first place.
2. I've done this. I got distracted by thinking about a work problem and/or was focused on the radio music. My "automatic pilot" kicked in and, instead of stopping at the doctor's office (~1 mile before the turnoff to the school), I did what I usually do 2x per day – drove to the school.
3. This one is easy (i.e., lot of options for added context).
   - Potential distractions, e.g.: Call coming in on the cell phone, passengers in car (*Bring Your Child to Work Day*?), etc.
   - Added challenges, e.g.: Rain/ice/snow, fogged or iced up windows, road construction.
   - Unexpected equipment problems, e.g.: "Fuel low" light comes on, run out of windshield washer fluid.

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- **How can we understand human error?**
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

How can we understand human error?

Lesson 1:

How can we understand human error?

Human error is <u>not</u> random.

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 93

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

How can we understand human error?

- But, why does human error <u>seem</u> random?
- Remember our exercise about context?
  - How many different possible contexts would you estimate can influence your everyday life?
  - For the actions typically addressed by HRA, the range of contexts has been <u>constrained</u> to:
    - Existing, licensed and operating nuclear power plants (NPPs)
    - NPP accidents represented in Level 1, at-power, internal events PRA
    - Actions taken by licensed operators
    - Operator actions taken (mostly) in the control room (that has been extensively designed and redesigned, reviewed and re-reviewed)
    - Operator actions that are addressed by Emergency Operating Procedures (EOPs) (that have been validated and demonstrated with decades of experience)
    - Operator actions that are adequately trained
    - Etc., etc., etc.

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 94

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

How can we understand human error?

Lesson 2:

How can we understand human error?

Human error is not the "cause" of a mishap.

How can we understand human error?

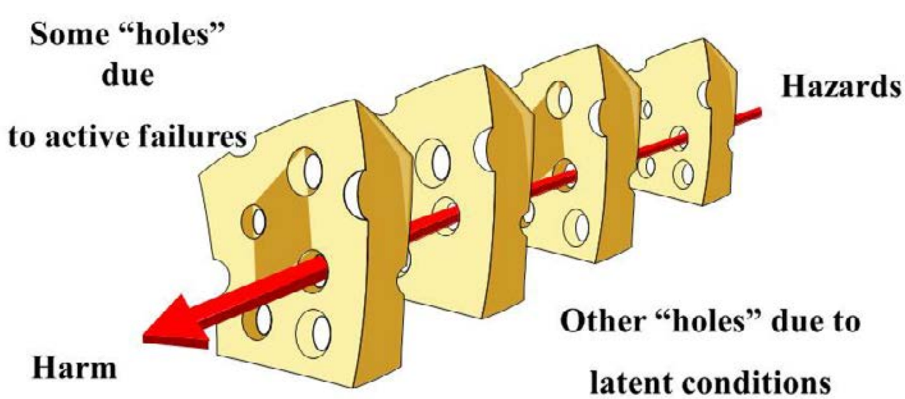
- Remember….

  - **The operator is often "set-up" for failure …**

  - **And, the operator is on the "sharp-end" (i.e., simply the last one to touch "the problem").**

- To illustrate this concept, here is Reason's Swiss Cheese model of event causation (1990 and 1997)

The 'Swiss Cheese' Model of Event Causation



Successive layers of defenses, barriers, & safeguards

How can we understand human error?

Lesson 3:

How can we understand human error?

Human error can be predicted.

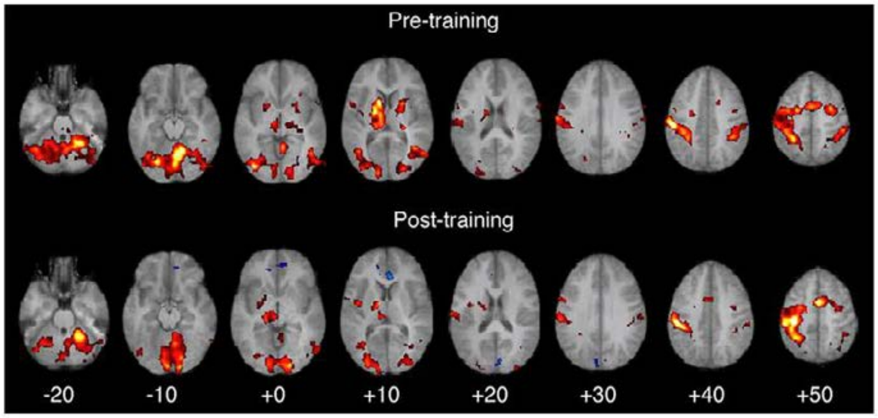
Human error can be predicted because…

- People's behavior is almost always rational
  - adaptive – i.e., goals are achieved
  - satisficing – i.e., best under the circumstances
- People's actions will tend to be
  - practical
    - people do what "works"
  - economical
    - people act so as to conserve resources
- And, in the case of NPPs, we have lots of rules and regulations to follow that are taken seriously; this further constrains likely behaviors and influences that HRA must model.

Human error can be predicted because…

- People follow familiar paths
    - Maximize use of habits (good *and* bad)
    - Minimize 'cognitive strain'
- People use 'rapid pattern-matching' to detect and interpret faults and errors
    - Very effective at detecting most problems, but
    - Not very effective at detecting our own errors
- People also use…
  - "shortcuts, heuristics, and expectation-driven actions."
  - efficiency-thoroughness trade-offs

Practiced actions become 'automatic'…



…whether we want them to or not.

How can we understand human error?

Lesson 4:

How can we understand human error?

By combining Lessons #1 through #3…

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 105

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

How can we understand human error?

Human errors are not isolated breakdowns, but rather are the result of the same processes that allow a system's normal functioning.

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 106

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

How can we understand human error… for HRA/PRA?

- First, previous PRA studies serves as guides for what types of operator actions are important to include in PRA models, what factors are the most important influences on operator performance, and so on.

- Second, HRA methods are developed principally for operators in NPPs; consequently, some basic understanding and expectations of NPP operator behavior, control room design, procedure use, operator training and education, etc. has been "built-in" the methods.

How can we understand human error… for HRA/PRA? (continued)

- Third, HRA methods attempt to bridge the gap between the real operational experience in NPPs and psychology by:
  - filtering out behaviors, performance influences, and other factors that are not typically important for operator response to accident scenarios modeled in PRAs
  - Providing the HRA analyst with a focused set of issues to address in NPP HRA/PRA
- Fourth, the HRA analyst should perform qualitative HRA tasks (i.e., make plant-specific assessments and observations of operator performance in order to identify which factors or issues are important for the specific plant and study).

How can we understand human error … for HRA/PRA? (continued)

- As part of qualitative analysis, the HRA analyst further develops an understanding and ability to predict operator actions by addressing…
  - The context for the operator action

- The context includes both:
  1. Plant/facility conditions, configuration, and behavior, and
  2. Operator behavior influencing factors (sometimes called "performance shaping factors" (PSFs), performance influencing factors (PIFs), or driving factors)

How can we understand human error … for HRA/PRA? (continued)

- Performance shaping factors usually capture important behavior-influencing aspects of, for example:
  - Time available (often not defined as a PSF, but a **very** important factor)
  - Procedures
  - Operator training
  - Human-machine interfaces
  - Action cues and other indications
  - Crew staffing and organization
  - Crew communication
- The important aspects of these factors can change with the plant/facility, NPP operation, operator action and location, etc.

How can we understand human error… for HRA/PRA? (continued)

- Then, the HRA analyst can match up the results of qualitative HRA with aspects of HRA quantification methods to predict <u>why</u> such potential operator failures might occur, e.g.,
  - Classifications, categories, or types of operator failures:
    - Errors of omission and commission (dependent on the PRA model for definition)
    - Slips/lapses, mistakes, and circumventions
    - Skill-, rule-, and knowledge-based errors
  - Explanations of operator failures using information processing models, e.g.,
    - Failures in detection, situation assessment, response planning, and/or response execution
  - Explanations of operator failures using a filtered set of "causes" (i.e., cause-based models)
  - Explanation of operator failures using performance shaping factors

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 111

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

How can we understand human error… for HRA/PRA? (continued)

- Which approach for explaining operator failure do you use?
  - **<u>Depends</u>** on a variety of factors but, especially, the type of operation or action being modeled.
  - Often helpful to use more than one way of classifying operator failure because different HRA quantification methods…
    - Use different classification and categorization schemes
    - Emphasize different PSFs, driving factors, or other elements of context
    - Represent different types of operator actions, behavior models, and so forth
  - Which approach helps to best explain why the HRA analyst thinks the operator might fail?

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 112

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

How can we understand human error?

- So, it's important for an HRA analyst to do his best to
  - "Understand the problem" by understanding the context, operator actions and potential failures or errors, etc. (i.e., perform some HRA qualitative analysis)
  - Match "the problem" to the HRA method that best represents the critical aspects of "the problem
- In other words, HRA method selection is important and should be done after you have some "understanding of the problem," including the likely operator actions and potential operator failures ("errors").
- In the next presentation topic, we'll summarize some of the important features of existing HRA methods.

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- **What are the important features of existing HRA methods?**
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

What are the important features of existing HRA methods?

- Attempt to reflect the following characteristics:
  - plant behavior and conditions
  - timing of events and the occurrence of cues for human action
  - parameter indications used by the operators and changes in those parameters as the scenario proceeds
  - time available and locations necessary to implement the human actions
  - equipment available for use by the operators based on the sequence
  - environmental conditions under which the decision to act must be made and the actual response must be performed
  - amount of directly relevant training and experience
  - applicability and usefulness of procedural or other guidance

What are the important features of existing HRA methods?

- Common US HRA methods:
  - Technique for Human Error Rate Prediction (THERP)
  - Accident Sequence Evaluation Program (ASEP) HRA Procedure
    - Simplification from THERP
  - Cause-Based Decision Tree (CBDT) Method
  - Human Cognitive Reliability (HCR)/Operator Reliability Experiments (ORE) Method
  - Standardized Plant Analysis Risk HRA (SPAR-H) Method
  - A Technique for Human Event Analysis (ATHEANA)

What are the important features of existing HRA methods?

- Overall, many HRA methods have been developed:
  - THERP (published in 1983) was first; developed to support first nuclear power plant PRA effort (WASH-1400 [1975])
  - Many methods developed in the 1990s to support a growing number of PRA studies (e.g., IPEs)
  - In the 2000s, HRA method development continued with a focus on cognitive/decision-making, e.g.,
    - So-called "second-generation" methods developed to capture advances in behavior and cognitive science
- In general, each HRA method represents (usually, implicitly), <u>as developed</u>:
  1. A perspective on human error (e.g., what performance shaping factors are important), and
  2. A snapshot in time (with respect plant design, operations, etc.).
- <u>As applied</u>, HRA methods have been used to represent human behavior in other timeframes, technologies, etc. – <u>must be cautious though!</u>

What are the important features of existing HRA methods?

- To-date, the principal focus of HRA methods development has been on supporting Level 1, at-power, internal events PRA.
- However, existing HRA methods have been applied to other kinds of problems:
  - Low power and shutdown HRA/PRA for nuclear power plants (e.g., NUREG/CR-6144 and NUREG/CR-6145).
  - NASA PRAs for space shuttle
  - DOE's license application for Yucca Mountain waste repository
- In some cases, these applications have explicitly expanded or adapted existing HRA methods (in recognition that the method is not being applied exactly as intended)
- And, there have been other cases….

THERP: Technique for Human Error Rate Prediction (NUREG/CR-1278, 1983)

- This is the most extensively documented and the most widely used (and misused) HRA technique. The handbook has four main sections:
  - Basic concepts.
  - Method for analysis and quantification of human performance.
  - Human performance models and HEPs.
  - Tables of HEPs and examples.
- Simplified version developed as "Accident Sequence Evaluation Program Human Reliability Analysis Procedure" in NUREG/CR-4772, 1987
  - Referred to as "ASEP"

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 119

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

THERP (continued)

- THERP:
  - Is applicable to pre- and post-Initiator HFEs
  - Provides a cognitive model based on time reliability correlations
- THERP models **execution errors** using task analysis, e.g.,
  - Tasks are reviewed to identify critical steps
  - Each critical step has two failure modes
    - Error of omission
    - Errors of commission
  - HFE can be represented in a HRA event tree
- THERP provides human error probabilities in Chapter 20 tables
  - <u>Intended</u> to be assigned as "branch" probabilities in HRA event tree
  - Limited number of PSFs used to adjust HEPs
  - Recovery and dependencies are addressed

Fire PRA Workshop 2012, Bethesda, MD
Principles of HRA

Slide 120

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

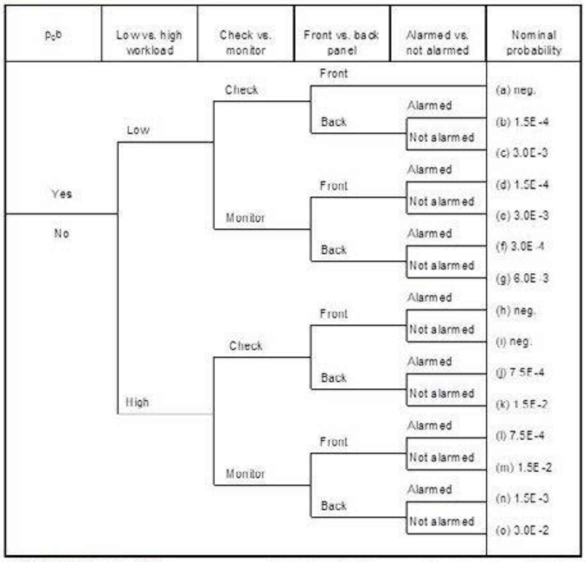
Caused Based Decision Tree (CBDT) Method (EPRI)

- CBDT consists of a series of 8 decision trees to address potential causes of errors, produces HEPs based on those decisions.
- Four (i.e., half) of the decision trees involve the man-machine cue interface:
  - Availability of relevant indications (location, accuracy, reliability of indications)
  - Attention to indications (workload, monitoring requirements, relevant alarms)
  - Data errors (location on panel, quality of display, interpersonal communications)
  - Misleading data (cues may not match procedure, need for training in cue recognition, etc.)

CBDT (continued)

- Another four decision trees involve the man-procedure interface:
  - Procedure format (visibility and salience of instructions, place-keeping aids)
  - Instructional clarity (standardized vocabulary, completeness of information, training provided)
  - Instructional complexity (e.g., avoid use of "not" statements, complex use of terms such as "and," "or," etc.)
  - Potential for deliberate violations (unquestioning belief in instructional adequacy, lack of awareness of availability and consequences of alternatives, etc.)
- For time-critical actions, the CBDT is supplemented by a time-reliability correlation (TRC)

Example CBDT decision-tree: data not attended to



EPRI HRA Calculator

- Software tool
- Uses SHARP1 as the HRA framework/HRA process
- Post-initiator HFE methods:
  - For diagnosis, uses CBDT (decision trees) and/or HCR/ORE (time based correlation)
  - For execution, THERP for manipulation
- Pre-Initiator HFE methods:
  - Uses THERP and ASEP to quantify pre-initiator HFEs

ATHEANA – NUREG-1624, Rev. 1 and NUREG-1880

- Provides an HRA process, an approach for identifying and defining HFEs (especially for EOCs), an HRA quantification method, and a knowledge-base (including analyzed events and psychological literature)
- Provides a structured search for problem scenarios and unsafe actions
- Focuses on the error-forcing context
- Uses the knowledge of domain experts (e.g., operators, pilots, operator trainers)

ATHEANA – NUREG-1624, Rev. 1 and NUREG-1880 (continued)

- Links plant conditions, performance shaping factors (PSFs) and human error mechanisms
- Consideration of dependencies across scenarios
- Attempts to address PSFs holistically (considers potential interactions)
- Structured search for problem scenarios and unsafe actions
- Developed by the USNRC:
  - NUREG-1624, Rev.1 was published first (2000) and is more detailed
  - NUREG-1880 was published later (2007), is a user's guide, and contains the full, expert elicitation quantification approach

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- **What are the HRA concerns or issues for fire PRA?**
- Any final questions?

What are the HRA concerns or issues for fire PRA?

What are the HRA concerns or issues for fire PRA?

- Actually, there are some different issues for HRA to address in fire PRA, such as:
  - New HFEs to identify, e.g.,
    - Fire response operator actions in fire procedures
  - Errors of Commission (EOCs) to identify and define, e.g.,
    - Per the Standard, the possibility that operators respond to spurious indications as if they are "real" must be considered.
    - Is there a way to limit the number of EOCs modeled in the fire PRA?
  - New environmental hazards to model as performance shaping factors (PSFs), e.g.:
    - Fire effects of smoke, heat, and toxic gases on operators
    - Impact of breathing apparatus and protective gear on operator performance, including communications
  - More challenging contexts, e.g.,
    - Potentially wide variations in size, location, and duration of fires and their effects on plant systems and functions

What are the HRA concerns or issues for fire PRA?

- Some different issues for fire HRA: (continued)
  - Different types of decisions, e.g.,
    - Operator judgment on whether to abandon the control room
  - Other PSFs or influencing factors, e.g.,
    - Design of ex-control room equipment control locations and alternate shutdown panels

- But, this, and more, will be addressed in the Fire HRA track, starting tomorrow.

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- **Any final questions?**

SPAR-H DIAGNOSIS WORKSHEET

Human Action: Operator fails to align SI/CS for Recirculation from the Containment Sump

Diagnosis HEP = 5.00E-04

PSFs	PSF Levels	Multiplier for Diagnosis		If non-nominal PSF levels are selected, please note specific reasons in this column
1. Available Time	Inadequate[a]	1.0		
	Barely adequate ≈2/3 x nominal	10		
	Nominal time	**1**	x	
	Extra time (between 1 and 2 x nominal and > than 30 min)	0.1		
	Expansive (> 2 x nominal and > 30 min)	0.01		
2. Stress	Extreme	5		Occurrence of "the" design basis event is expected to elevate stress levels. At this point there is no threat to personnel safety so "High" is selected.
	High	**2**	X	
	Nominal	1		
3. Complexity	Highly	5		Symptoms of a LOCA are obvious and well known.
	Moderately	2		
	Nominal	1		
	Obvious diagnosis	**0.1**	x	
4. Experience/Training	Low	10		Design basis LOCAs are integral part of operator training.
	Nominal	1		
	High	**0.5**	x	
5. Procedures	Not available	50		Procedures are clear and designed for such scenarios.
	Incomplete	20		
	Available, but poor	5		
	Nominal	1		
	Diagnostic/symptom oriented	**0.5**	X	
6. Ergonomics	Missing/Misleading	50		
	Poor	10		
	Nominal	**1**	X	
	Good	0.5		
7. Fitness for Duty	Unfit[a]	1.0		
	Degraded Fitness	5		
	Nominal	**1**	X	
8. Work Processes	Poor	2		
	Nominal	**1**	X	
	Good	0.8		

a - Total failure probability = 1.0, regardless of other PSFs

SPAR-H ACTION WORKSHEET

Human Action: Operator fails to align SI/CS for Recirculation from the Containment Sump

Action HEP = 1.00E-04

PSFs	PSF Levels	Multiplier for Diagnosis		If non-nominal PSF levels are selected, please note specific reasons in this column
1. Available Time	Inadequate[a]	1.0		Action itself is very quick: opening of a valve. Given the 17 minutes available, this is ample time.
	Time available ≈ time required	10		
	Nominal	1		
	Available > 5x time required	**0.1**	X	
	Available > 50x time required	0.01		
2. Stress	Extreme	5		Occurrence of "the" design basis event is expected to elevate stress levels. At this point there is no threat to personnel safety so "High" is selected.
	High	**2**	X	
	Nominal	1		
3. Complexity	Highly	5		
	Moderately	2		
	Nominal	**1**	X	
4. Experience/Training	Low	3		Design basis LOCAs are integral part of operator training.
	Nominal	1		
	High	**0.5**	X	
5. Procedures	Not available	50		
	Incomplete	20		
	Available, but poor	5		
	Nominal	**1**	X	
6. Ergonomics	Missing/Misleading	50		
	Poor	10		
	Nominal	**1**	X	
	Good	0.5		
7. Fitness for Duty	Unfit[a]	1.0		
	Degraded Fitness	5		
	Nominal	**1**	X	
8. Work Processes	Poor	2		
	Nominal	**1**	X	
	Good	0.5		

a - Total failure probability = 1.0, regardless of other PSFs

Diagnosis HEP =	5.00E-04
Action HEP =	1.00E-04
Total HEP =	6.00E-04

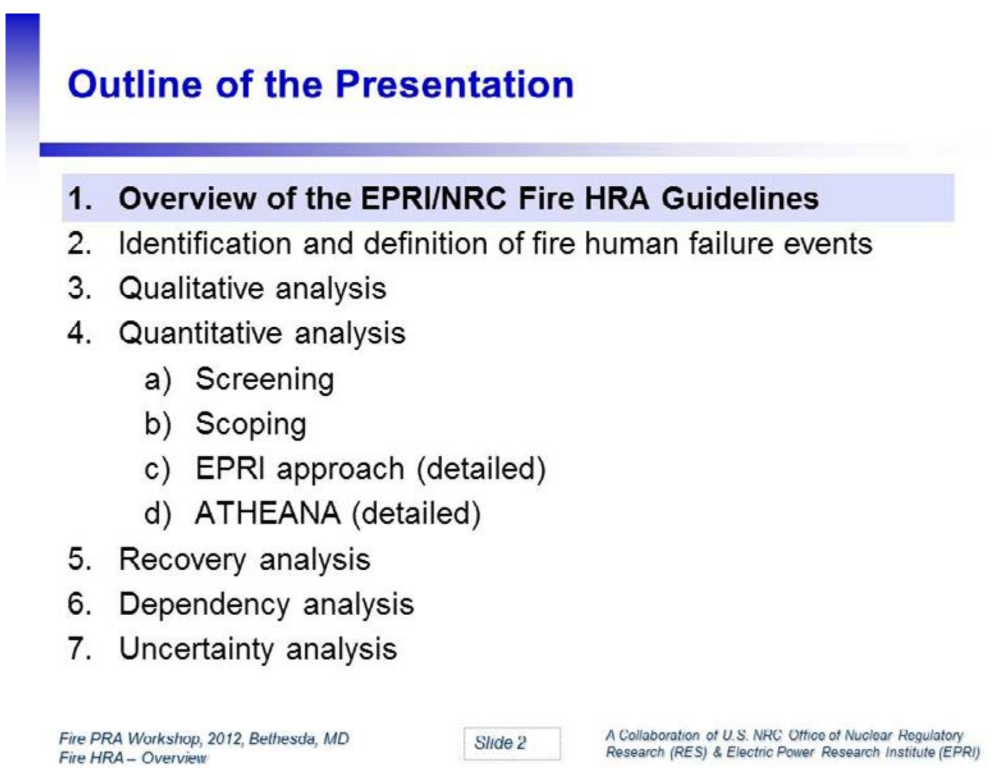
3
MODULE 4 HRA

The following is a short description of the Fire PRA technical tasks covered in Module 4. For further details relative to this technical task, refer to the individual task descriptions in Volume 2 of EPRI 1011989, NUREG/CR-6850.

- ***Post-Fire Human Reliability Analysis (Task 12).*** This task considers operator actions for manipulation of plant components. The analysis task procedure provides structured instructions for identification and inclusion of these actions in the Fire PRA. The procedure also provides instructions for incorporating human error probabilities (HEPs) into the fire PRA analysis.

Note that NUREG/CR-6850, EPRI 1011989 did not develop a detailed fire HRA methodology. Training module 4 is instead based on a joint EPRI/RES project as documented in NUREG-1921, EPRI 1023001, *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines.*

3.1. Fire HRA Training Overview



EPRI/NRC Fire HRA Guidelines Overview

- Purpose of the Fire HRA training course module
- Training objectives
- Background on the Fire HRA Guidelines
- Fire HRA development team, approach & timeline
- Fire HRA Guidelines, public review & path forward
- Summary of EPRI/NRC Fire HRA Guidelines scope & contents

EPRI/NRC Fire HRA Guidelines
Purpose of Training Course

- Provide training on guidance from EPRI/NRC Fire HRA Guidelines (NUREG-1921/EPRI 1023001)
- Opportunity for face-to-face, real-time interactions between authors and potential future users
- Opportunity to improve training
  - It is important for us to get student/audience feedback for future presentations

Fire HRA Module Training Objectives

1: Be able to name the **steps in the process** for conducting a Fire HRA.

2: Be able to list the **different categories** of fire HRA human failure events.

3: Demonstrate a knowledge of ASME/ANS PRA Standard **high level requirements** related to HRA.

4: Be able to identify **context and performance shaping factors** used in the analysis of fire human failure events.

5: Be able to list the **quantification methods** available for HEPs.

6: Understand the concept and importance of addressing **dependencies** between fire HRA events.

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Overview

Slide 5

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Background on the Issue of Fire HRA

- Almost 50% of USA plants transitioning to NFPA-805
  - Using NUREG/CR-6850 [EPRI 1011989] for the Fire PRA Guidance
- NUREG/CR-6850 [EPRI 1011989] addresses:
  - Identifying human failure events (HFEs)
  - Assigning conservative screening human error probabilities (HEPs)
  - Fire Performance Shaping Factor (PSF) information
- NUREG/CR-6850 [EPRI 1011989] does not:
  - Describe a methodology for developing best-estimate HEPs (given fire related effects)
  - Address the requirements of:
    - ASME/ANS RA-Sa-2009, "Addenda to ASME/ANS RA-S-2008, Standard for Level 1 / Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," Chapter 4 for fires
- Consequently, there was a need for fire-specific guidance for best-estimate HRA quantification in fire PRA

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Overview

Slide 6

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

EPRI/NRC Fire HRA Guidelines
High Level Objectives

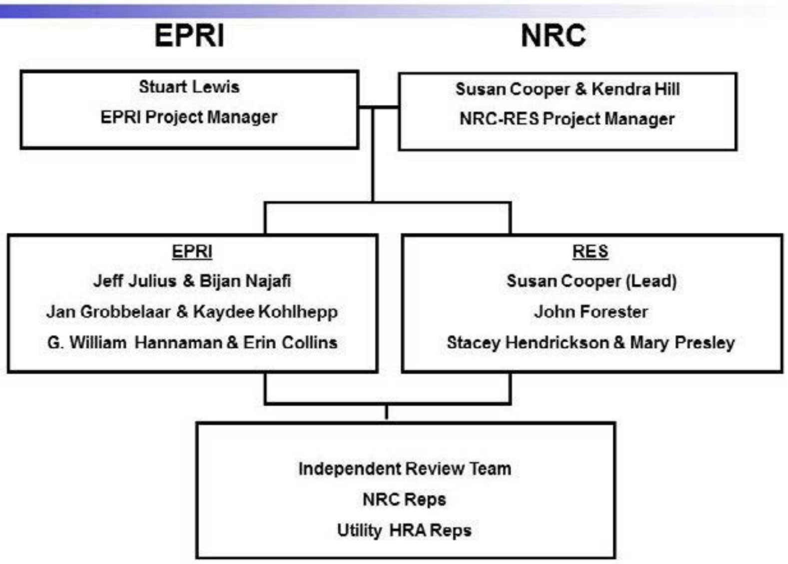
- Through joint NRC and industry efforts, address the need for HRA guidance, especially for best-estimate quantification, for use in fire PRAs
  - Address methodology
  - Address guidance for implementing the methodology
- Develop a joint EPRI/NRC report (similar to NUREG/CR-6850 [EPRI 1011989])
- Consider ASME/ANS PRA Standard requirements and user needs

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Overview

Slide 7

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

EPRI/NRC Fire HRA Guidelines
Development Team



Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Overview

Slide 8

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Guidelines Development Approach

1) Fire Generic Data Review
   - Existing guidance & literature
   - Historical & experiential plant fire data
2) Fire HRA Methodology & Guidelines Development
   - Examined HRA process & identified how process and tasks would change for the fire environment and accident response scenarios in response to a fire
3) Fire HRA Review & Test
   - NRC and industry peer review team (7 people)
   - Two plants tested Scoping method flowcharts

Fire HRA Guidelines Development Timeline

- Started March 5, 2007
- First integrated draft - May 2008
- Peer review - June 2008
- Testing at 2 plants - Summer/Fall 2008
- Revised draft - April 2009
- Quick review by NRR and NRO – April 2009
- Piloting by PWR Owner's Group – Summer 2009
- Public comment period - December 2009 to March 2010
- ACRS presentations
  - Sub-committee: June 2009; April and September 2011
  - Full committee: April 2012
- *Training Courses:*
  - *1st presentation in September and October 2010*
  - *2nd presentation in August and November 2011*
  - *3rd presentation in July and September 2012*
- *Publication of final report – June or July 2012*

Fire HRA Guidelines Public Review & Comment

- NUREG-1921/EPRI 1019196 issued in November 2009 for public review and comment
- Prior to public review period, obtained comments during presentation to ACRS PRA Subcommittee
- Received 265 public comments (~75 editorial) from:
  - PWROG
  - BWROG
  - EPRI HRA User's Group
  - Exelon
- Final report was revised to address public comments, etc.
  - Approach is not fundamentally different, but
  - Some important changes (e.g., reduced requirements for assessing feasibility of operator actions during screening and scoping analyses)

Fire HRA Guidelines Path Forward

- Final Guidelines document to be issued in 2012
- It is anticipated that this guidance will be used by the industry as part of transition to NFPA 805 and possibly in response to other regulatory issues
- This is the first report addressing fire-related HRA for fire PRA that goes beyond the screening level
- As the methodology is applied at a wide variety of plants, the document may benefit from future improvements to better support industry-wide issues being addressed by fire PRA

Fire HRA Guidelines Summary
Objectives and Scope

- Identify/analyze **existing post-initiator** HFEs
  - Changes to previously modeled HFEs due to fire effects
- Identify/analyze **post-initiator fire response** HFEs
  - New category of HFE to be analyzed
    - Procedures, training, cues typically different from existing post-initiator HFEs
  - Includes alternative shutdown (such as MCR abandonment due to habitability or transferring command and control to outside the MCR)
- Identify/analyze **post-initiator HFEs in response to spurious actuations and indications**
  - New category of HFE to be analyzed

Fire HRA Guidelines Summary
Objectives and Scope (continued)

- Implement post-initiator fire HEPs in fire PRA model(s)
  - Initial quantification using screening or scoping approach
  - Identification of risk significant events for later detailed HRA (e.g., to meet ASME/ANS Part 2 supporting requirement HR-G1, Capability Category II)
  - Including dependency analysis
- Out of Scope
  - Pre-initiators (per NUREG/CR-6850 [EPRI 1011989])
  - Fire brigade response (except for impacts on fire PSFs)

Fire HRA Guideline Summary

- Standard HRA **process** used for Fire HRA modeling:
  - Based on other processes and guidance
    - ASME/ANS PRA Standard
    - NUREG-1792
    - Fire Manual Actions, NUREG-1852
    - SHARP1
    - ATHEANA
- Overall, NUREG-1921 [EPRI-1023001] captures the state-of-practice in HRA then advances the state-of-the-art for fire-specific PRA purposes

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Overview

Slide 15

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Process Steps

1. **Identification & definition** of human failure events (HFEs):
   - Substantial guidance provided, including feasibility test
   - Feasibility Evaluation (Go / No-Go) example criteria
     - Sufficient time available to complete action
     - Procedures & cues exist
     - Sufficient manpower
2. **Qualitative analysis**
   - Iterative process that continues throughout quantification steps
   - Discussion includes tips & tools for information collection, & interpretation, addressing important fire-specific topics, etc.
   - Comprehensive discussion of HFE feasibility under fire conditions
   - As fire PRA develops, fire HRA must consider additional fire scenario-specific details that become available

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Overview

Slide 16

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Process Steps (continued)

3. Quantification Methods – three levels

- **Screening Quantification**
  - Refinement/relaxation for areas identified in NUREG/CR-6850 [EPRI 1011989] implementation
  - Typically used in NUREG/CR-6850, Task 7 first/screening quantification
- **Scoping Fire HRA** method added (new):
  - Developed to address the majority of HFEs, thereby conserving HRA resources
  - Simplified HRA quantification method with limited set of performance shaping factors (PSFs) to address
  - Decision tree format (enhancing traceability)
  - Typically used during NUREG/CR-6850, Tasks 7 or 8, or early quantification of detailed fire scenarios in Tasks 11/14

Fire HRA Process Steps (continued)

3. Quantification (cont'd, 3rd of 3 methods)

- **Detailed Fire HRA**
  - Uses existing methods
  - Performance shaping factors modified for the fire context:
    - EPRI Cause-Based Decision Tree & HCR/ORE; & THERP
    - NRC's ATHEANA HRA method
  - Typically used in NUREG/CR-6850 [EPRI 1011989] Tasks 11/14 quantification of detailed fire scenarios as needed

Fire HRA Process Steps (continued)

4. **Recovery, Dependency, and Uncertainty**
   - Typically part of NUREG/CR-6850 [EPRI 1011989] Tasks 11/14 quantification of detailed fire scenarios
   - In general, these tasks are not different than that for internal events PRA
   - NUREG-1921 [EPRI 1023001] discusses fire-specific aspects of these tasks

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Overview

Slide 19

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Process Steps

NUREG/CR-6850 [EPRI 1011989] Task	Fire HRA Process Step
Task 2 – Component Selection	**Identification** of previously existing HFEs & potential response to spurious
Task 5 – Fire-Induced Risk Model	**Identification and Definition** of fire response HFEs
Task 12 – Fire HRA	**Qualitative Analysis** - context & performance shaping factors
Task 7 – First/Screening Quant.	**Quantification** – typically screening or scoping
Task 8 – Scoping Quantification	**Quantification** – typically scoping
Tasks 11/14 – Detailed Scenario Quantification	**Quantification & Dependency** could be screening, scoping or detailed HRA
Task 15 – Uncertainty	**Uncertainty**

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Overview

Slide 20

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Guideline Summary

- NUREG-1921 [EPRI 1023001] also provides some additional tools & discussion that may be helpful to the analysis, e.g.,
  - Section 2.3, Relationship to Other Fire PRA Tasks
    - More detailed discussion of relationship between HRA and fire PRA
    - Table 2-1 relates NUREG/CR-6850 tasks to ASME/ANS PRA Standard elements & HRA tasks
  - Section 2.5, Fire-Induced Cable Failure(s) and Electrical Faults
    - Discussion of how fire PRA treats fire-induced cable failure(s)
    - Table 2-2 relates different types of fire damage to different fire PRA tasks & how this damage is addressed

Fire HRA Guideline Summary

- NUREG-1921 [EPRI 1023001] also provides some additional tools and discussion… (continued)
  - Section 4.3, Feasibility Assessment
    - Feasibility is defined & criteria are identified
    - Discussion of how feasibility assessments can be performed
  - Section 4.6.2, Timing
    - Discussion of timing windows used in NUREG-1921 [EPRI 1023001] quantification methods
    - Discussion of how to develop timing information
  - Section 4.11, Reviews with Plant Operations
    - Discussion on how to conduct talk-throughs & walk-throughs

Fire HRA Technical Overview

- **Fire HRA Process Summary:**
  - Identification and Definition
  - Qualitative Analysis
  - Quantification Methods:
    - Screening
    - Scoping
    - Detailed
  - Recovery, Dependency, & Uncertainty
- Each Fire HRA process step is further described in subsequent presentations

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI

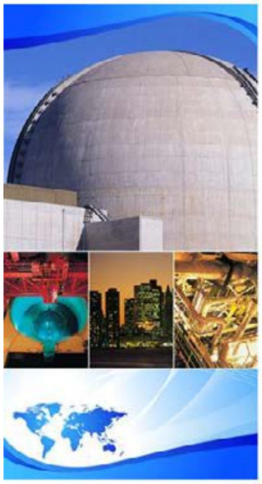
CURTISS WRIGHT Flow Control Company
SCIENTECH

Sandia National Laboratories

SAIC® Science Applications International Corporation
From Science to Solutions™

3.2. Identification and Definitions of Fire Human Failure Events

ELECTRIC POWER RESEARCH INSTITUTE



EPRI/NRC-RES FIRE PRA METHODOLOGY
Task 12 – Fire HRA

Identification and Definition of Fire Human Failure Events

Joint RES/EPRI Fire PRA Workshop 2012
Bethesda, MD

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Course Overview

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. **Identification and Definition of fire human failure events**
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – Identification & Definition

Slide 2

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Module Training Objectives

1: Be able to name the **steps in the process** for conducting a Fire HRA.

2: Be able to list the **different categories** of Fire HRA human failure events.

3: Demonstrate knowledge of ASME/ANS PRA Standard **high level requirements (HLRs).**

- For the HLRs associated with Identification and Definition

4: Be able to identify **context and performance shaping factors** used in the qualitative analysis of fire human failure events.

5: Be able to list the **quantification methods** available for HEPs.

6: Understand the concept and importance of addressing **dependencies** between fire HRA events.

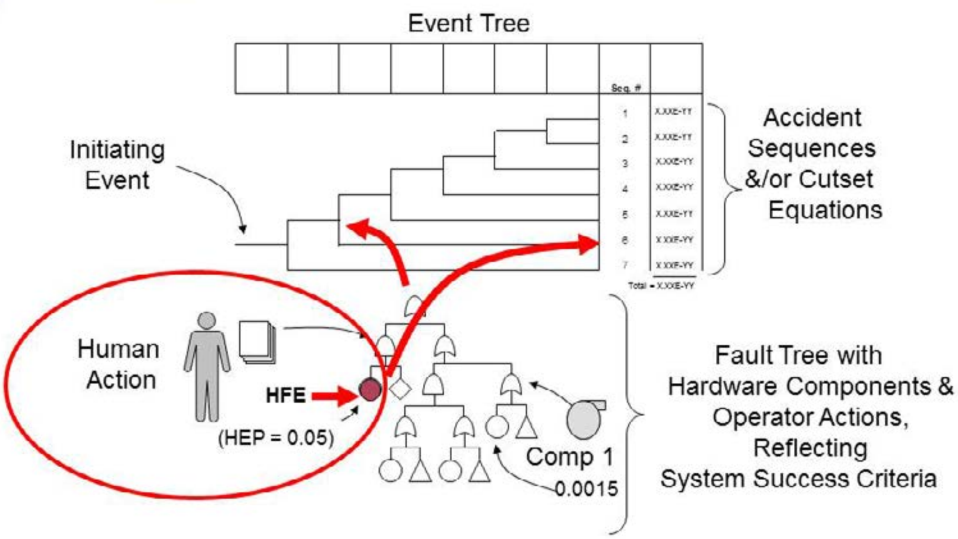
Outline of the Identification/Definition Module

- Introduction/Relation to NUREG/CR-6850 (EPRI 1011989) Tasks
- Applicable PRA Standard High Level Requirements
- Identification
- Categories of Fire Human Failure Events
- Definition and Fire Context
- Feasibility – Initial Assessment
- Summary

Introduction – What is ***Identification***?

- Human Reliability Analysis starts with developing understanding of role(s) of operators in responding to an event
- Actions relevant to post-initiator (after a fire) response are identified via:
  - Review of plant emergency and other operating procedures such as Fire Response procedures
  - Review of PRA Event trees, Fault trees, and Results (sequences and/or cutsets)
  - Operator interviews
- Once relevant actions are understood, corresponding ***human failure events*** are ***identified*** for inclusion in the PRA models

Introduction – Depiction of Identification



PRA Standard Requirements for ***Identification***

Relevant HLRs from Internal-Events Section (Ch. 2 of Standard)

HLR-**HR**-E

A **systematic review** of the **relevant procedures** shall be used to identify the set of operator responses required for each of the accident sequences

Relevant HLRs from Fire Section (Ch. 4 of Standard)

HLR-**HRA**-A (from the HRA element)

The Fire PRA shall identify human actions relevant to the sequences in the Fire PRA plant response model

HLR-**ES**-C (from the Equipment Selection element)

The Fire PRA shall identify instrumentation whose failure including spurious operation would impact the reliability of operator actions associated with that portion of the plant design to be credited in the Fire PRA.

Introduction – What is ***Definition***?

- After HFE Identification, ***Definition*** gives the initial basis for justifying inclusion of the action in the PRA model.
- Consists of objective, qualitative data:
  - Procedures
  - Cues (the prompts to initiate actions)
    - Alarms, indications, and/or procedure steps
  - Timing (Time Available and Time Required)
  - Staffing (may require more than for internal event response)
- Provides input to the subsequent Qualitative Analysis of the factors affecting human reliability
- Requires Initial Feasibility Evaluation

PRA Standard Requirements for Definition

Relevant HLRs from Internal-Events Section (Ch. 2 of Standard)

HLR-**HR**-F

Human failure events shall be defined that represent the impact of not properly performing the required responses, consistent with the structure and level of detail of the accident sequences.

Relevant HLRs from Fire Section (Ch. 4 of Standard)

HLR-**HRA**-B

The Fire PRA shall include events where appropriate in the Fire PRA that represent the impacts of incorrect human response associated with the identified human actions.

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – Identification & Definition

Slide 9

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Process Steps

NUREG/CR-6850 Task	Fire HRA Process Step
Task 2 – Component Selection	**Identification of previously existing HFEs & potential response to spurious actuations/signals**
Task 5 – Fire-Induced Risk Model	**Identification & Definition of Fire Response Actions**
Task 12 – Fire HRA	**Qualitative Analysis:** starts with **context definition**
Task 7 – First/Screening Quant.	**Quantification –** typically screening
Task 8 – Scoping Quantification	**Quantification –** typically scoping
Tasks 11/14 – Detailed Scenario Quantification	**Quantification & Dependency** could be screening, scoping or detailed HRA
Task 15 – Uncertainty	**Uncertainty**

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – Identification & Definition

Slide 10

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Categories of Fire Operator Actions

1. Existing operator actions from the internal events PRA
   - From the Level1/LERF PRA model used to develop the Fire PRA
   - To be modified for fire effects
2. Fire Response Actions
   - New actions contained in the fire procedures
   - New actions to address recovery of spurious actuation
   - MCR abandonment is a subset of fire response actions
3. HFEs Corresponding to Undesired Operator Responses
   - New actions to address undesired operator actions in response to spurious indications per Fires (Ch. 4) in the ASME/ANS Combined PRA Standard
   - EOCs are specifically addressed in FPRA

Identification of Fire PRA HFEs (General)

Review plant response and PRA model:

- Review Event Tree Sequences with applicable procedure/s:
  - Understand operator requirements to control plant response
    - Functions or systems manually initiated, controlled, or isolated
  - Typically a function of the initiating event
- Review System Fault Trees with applicable procedure/s:
  - Understand what is required of operators in controlling system or component response
    - Functions manually initiated or controlled
    - Potential recovery (e.g., align standby or alternate)
  - Typically independent of initiating event
- Review PRA Results sequences and cutsets
- Discussions with Operators to confirm operator response

Identification of Fire PRA HFEs (General cont'd)

Review ET sequences, system FT, and PRA results to:

1. Understand what the operators are doing
2. Identify **cue(s)**, **procedure steps**, **and time window**
3. Identify procedural path leading to the step with cue
4. Document the PRA **context** from Event or Fault Tree
   - Initiating event
   - Preceding operator actions in the sequence
   - Hardware/system successes and failures

Good Practice (collect if the data is available)

- Identify secondary cues or alternate success paths
  - Examples: Critical Safety Function Status Trees, alarms or indications.

Review of Plant Operations and PRA Data

- Best Practice for HRA analysts to confirm with plant **operations personnel** at the start of the HRA:
  - Staffing during fire (number of operators and roles)
  - Procedural usage for fire (EOPs, AOPs, and Fire Response)
  - Main control room (MCR) staff interaction with fire brigade
  - Expected MCR staff response after detection of fire
  - Review of plant-specific fire history for insights
- Review of **PRA Information**:
  - Additional information, beyond Event and Fault Trees
  - Success criteria: Determine Time Window (Time Available)
  - Internal events HRA: to understand initial model basis

Identification: Operator Actions in Internal Events PRA

- Identify fire-induced initiating events included the FPRA
  - Done in NUREG/CR-6850 (EPRI 1011989) Tasks 2 & 5
  - Examples of actions carried into the FPRA
    - General transients which may include spurious SI actuation
    - Loss of support system(s), e.g., loss of instrument air or loss of electrical bus
    - LOCA (e.g., due to spuriously opened relief valve)
    - Station blackout
- Identify operator actions modeled as delineating the plant response to the fire-induced initiators.
  - In event trees, fault trees, and in cutset recovery
- Includes manual start of safe shutdown components
  - Sometimes these are not "pre-existing" in the current PRA

Fire HFEs from Internal Events PRA - Examples

INCLUDE

- Open a steam dump or steam relief valve and conduct a post-LOCA cooldown
- Manual start of an emergency diesel generator
- Manual start of auxiliary feedwater following automatic actuation failure
- Manually align a back-up power supply

EXCLUDE

- Actions associated with internal events initiated not included in FPRA, for example:
  - Operators fails to diagnosis SGTR or RPV rupture

Identification:
Fire Response Operator Actions

- Required in response to a fire, as directed by the fire procedure(s), such as
  - Mitigate or prevent damage to equipment (e.g., pump dead-heading from fire-induced spurious valve closure)
  - Mitigate the effects of spurious indications or actuations (e.g., shut off above pump)
  - Abandon main control room and perform safe shutdown outside the main control room
- Identification process can be
  - Iterative as required in fire PRA strategy
    - Often not credited during initial quantification
  - Comprehensive based on fire procedure/s
- Examples on next slide

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – Identification & Definition

Slide 17

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire Response Action Examples

- Identify protected instrumentation channels (to mitigate spurious indications)
- Defeat solid state protection system (to prevent spurious safety injection)
- Control auxiliary feedwater locally by throttling valves manually and starting / stopping pumps
- Place remote shutdown location back-up indication panels in service
- Obtain steam generator level locally
- De-energize all ADS valves
- Close HPCI steam supply valve locally
- Align 4 kV bus by locally operating breakers

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – Identification & Definition

Slide 18

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Identification:
MCR Abandonment Actions

- MCR abandonment actions are a sub-set of fire response
- Operators will abandon if control room becomes uninhabitable, or due to loss of required control
- Identification process can be
  - Iterative as required in fire PRA (e.g. if additional spurious actuations are identified requiring mitigation)
  - Comprehensive based on review of the MCR abandonment procedure
- Some FPRAs credit scenarios where the operators remain in the control room for monitoring and announcing; but perform local actions
  - In this case the fire specific scenario is to be identified and defined by the FPRA analyst
  - HRA analysts identify the procedure guidance operators will follow

Identification: HFEs Corresponding to Undesired Operator Response to Spurious Signals

- An undesired operator action is *a well intentioned operator action, taken in response to a spurious indication, that unintentionally exacerbates the scenario*
  - Operators are generally trained to (1) believe their instrumentation and (2) follow their procedures
- Identified within the context of the accident progression
  - Review annunciator response procedures (primarily)
  - Review emergency operating procedures (best practice)
- Defined in terms of their impact on the function, system, train or component.
  - Although these actions are well-intended and not operator errors as such, the undesired consequences have the same impact as an error & are therefore modeled as HFEs

Identification and Definition of Factors for Undesired Operator Response to Spurious Signals

- Cue parameter/s
  - Single or multiple (redundant or diverse)
- Cue (procedural) hierarchy
  - Continuously monitored or procedurally checked only
- Cue verification
  - Required for immediate actions
- Degree of redundancy/diversity for a given parameter
  - Redundant/diverse channels mitigate consequences of single spurious indication

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – Identification & Definition

Slide 21

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Examples of Potential HFEs from a Review of Annunciator Procedures to Identify Undesired Operator Responses

Spurious Annunciator	Undesired Action	Consequence
ESW PUMP MOTOR INSTANT TRIP	Place the affected pump's control switch in LOCKOUT.	One train of service water stopped, thereby reducing ESW prob. of success in CCDP calculation. Can be restarted.
CCW PUMP MOTOR INSTANT TRIP	Place the affected pump's control switch in LOCKOUT.	Stopping one CCW pump increases operating temp. on many components in CCDP calculation. Can be restarted.
EAST RHR PUMP SUCTION VALVES NOT FULL OPEN	Immediately open 1-IMO-310, East RHR Pump Suction, or 1-ICM 305.	Depending on scenario (size of LOCA or not) could lead to cavitation of the pump. Loss of pump in Recirc. mode
RHR PUMPS MOTOR INSTANT TRIP	Place pump control switch in LOCK-OUT.	Delay start of RHR if not on or halts RHR if on. Impacts CCDP. Can be manually started.

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – Identification & Definition

Slide 22

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Human Failure Event Definition (General)

- Define a set of HFEs as unavailabilities of functions, systems or components as appropriate to the level of detail in the accident sequence and system models
- Include in the definition:
  - Accident sequence specific timing of cues, and time window for successful completion, and
  - Accident sequence specific procedural guidance (e.g., AOPs, and EOPs), and
  - The availability of cues and other indications for detection and evaluation errors, and
  - The specific detailed tasks (e.g., component level) required to achieve the goal of the response. (Cat III)
- Cognitive and execution elements

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – Identification & Definition

Slide 23

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Definition during Fire PRA Tasks

- HFE Definition starts during Identification with:
  - Cues/alarm or other indications, Procedure, Staffing, Time available
- Feasibility evaluation initially done during Definition, then expanded as HFE is developed
- The HFE Definition sets the Context for the HRA evaluation
- Fire PRA Context typically varies with NUREG/CR-6850 (EPRI 1011989) task
  - **Context starts in Definition & continues during Qualitative Analysis**
  - Task 7a – Screening HEPs often use qualitative info from Definition
  - Task 12 – Scoping HRA often uses qualitative info (context and PSF) associated with the scoping HRA trees
  - Task 14 – For risk significant HFEs perform Detailed HRA using qualitative context & PSFs associated with the detailed quant. method

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – Identification & Definition

Slide 24

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Definition during a Fire PRA

- Definition of existing internal events HFEs should be reviewed and revised for fire-specific impacts
- New fire response HFEs require definition
- Definitions should include:
  - Fire impact on instrumentation and indications used for detection, diagnosis and decision-making
  - Fire impact on timing of (1) cues, (2) response, (3) execution, and on (4) time available
  - Fire impact on success criteria
  - Fire impact on manpower resources, which affect recovery
  - Fire impact on local actions, e.g., accessibility, atmosphere, lighting
- Some data may not be initially available, but will be filled in during Qualitative Analysis

Initial Assessment of Feasibility

- Purpose: To decide whether an operator action can be accomplished or not, given the plant-specific and scenario-specific fire impacts.
- Feasibility Evaluation – Set HEP to 1.0 for any of the following (as the action would not be feasible)
  - Failed **instrumentation** (so no cues for operator action)
  - Insufficient **time available** to complete action
  - Insufficient **manpower**
  - **Procedural guidance** does not exist
  - Other Factors that may preclude credit
    - Fire is in same location as required actions
    - Inaccessible tools or equipment
- Feasibility is like a "continuous action step" that is re-visited as the NUREG-6850/EPRI 1011989 tasks progress.

Identification and Definition Summary

- HFE ***Identification*** finds where operator actions occur
  - In the plant response to initiating events included in the PRA model
- Identification consists of:
  - Review plant operating procedures and understand operator response
  - Review PRA Event trees, Fault trees, Results and Success Criteria
- HFE ***Definition*** gives the initial justification for inclusion of the action in the FPRA and provides input to Qualitative Analysis
- Definition consists of documenting objective, qualitative data:
  - Procedures
  - Cues
  - Timing
  - Staffing
- Initial Feasibility Evaluation is the Go/No-Go check

Course Overview

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. **Identification and Definition of fire human failure events**
3. Qualitative analysis **– NEXT!**
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

3.3. Qualitative Analysis

Outline of the Presentation

1. Overview of the EPRI/NRC-RES Fire HRA Guidelines
2. Identification and definition of fire human failure events
3. **Qualitative analysis**
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

Fire HRA Module Training Objectives

1: Be able to name the **steps in the process** for conducting a fire HRA.

2: Be able to list the **different categories** of fire HRA human failure events (HFEs).

3: Demonstrate a knowledge of ASME/ANS PRA Standard **high level requirements** for fire PRA.

4: Be able to identify **context and performance shaping factors** (PSFs) used in the analysis of fire human failure events.

5: Be able to list the **quantification methods** available for developing human error probabilities (HEPs).

6: Understand the concept and importance of addressing **dependencies** between fire HRA events.

Outline of the Qualitative Analysis Module

- Introduction
- Applicable PRA Standard High Level Requirements
- Elements of or tools for performing qualitative analysis per NUREG-1921/EPRI 1023001*
- Operator performance influencing factors and special topics in NUREG-1921

* For brevity, NUREG-1921 is used for the remainder of the presentation

Qualitative Analysis - Introduction

- Qualitative analysis is an essential part of HRA
  - Not always explicitly defined as a separate step
  - But, provides a foundation for **all** steps in the HRA process
- The objective of HRA qualitative analysis is to:
  - Understand the PRA context for each HFE
  - Understand actual "as-built, as-operated" response of operator and plant
  - Translate this understanding into factors, data, and elements used in HRA quantification methods
- Qualitative analysis tasks are performed constantly and iteratively throughout the HRA

Qualitative Analysis - Introduction (continued)

- For fire PRA, HRA qualitative analysis includes*:
  1. Review and refine (if needed) the fire-specific context (e.g., evaluate applicability of internal events HFEs)
  2. General information collection
  3. Review of historical experience
  4. Review and refine (if needed) plant operations input
  5. Assess feasibility of operator actions for new (or existing) HFEs in fire context
  6. Identify performance shaping factors (PSFs) and other contextual factors specific to fire HRA/PRA

* New or redefined qualitative analysis tasks specific to fire context are in blue font

Qualitative Analysis – Introduction (continued)

- Qualitative analysis results support all HRA products:
  - Identification and definition of HFEs
  - Selection of appropriate quantification methods
  - Quantification of HFE probabilities
  - Documentation of HRA overall
- Regardless of the HRA quantification method, qualitative information is needed
- All PSFs addressed in Part 2 of the PRA Standard (high-level requirements HR-F and HR-G) need to be considered, but may or may not be explicitly used during quantification

Applicable HLRs (from the PRA Standard*)
Qualitative Analysis

Relevant HLRs from Internal-Events Section (Part 2) of PRA Standard*

- HLR-AS-A: The accident sequence analysis shall describe the plant-specific scenarios that can lead to core damage following each modeled initiating event. These scenarios shall address system responses and operator actions, including recovery actions that support the key safety functions necessary to prevent core damage (11 SRs)
- HLR-HR-E: A systematic review of the relevant procedures shall be used to identify the set of operator responses required for each of the accident sequences (4 SRs)
- HLR-HR-F: Human failure events shall be defined that represent the impact of not properly performing the required responses, in a manner consistent with the structure and level of detail of the accident sequences (2 SRs)

* ASME/ANS RA-Sa-2009, "Addenda to ASME/ANS RA-S-2008, Standard for Level 1/Large Early Release Frequency PRA for Nuclear Power Plant Applications"

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Post-Fire HRA – Qualitative Analysis

Slide 8

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Applicable HLRs (per the PRA Standard)
Qualitative Analysis (Continued)

Internal Events (non-fire) HLRs (cont'd)

- HLR-HR-G: The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence. (8 SRs)

Relevant HLRs from Fire Section (Part 4) of PRA Standard

- HLR-HRA-B: The Fire PRA shall include events where appropriate in the Fire PRA that represent the impacts of incorrect human responses associated with the identified human actions (2 SRs; consistent with HLR-HR-F)
- HLR-HRA-C: The Fire PRA shall quantify HEPs associated with the incorrect responses accounting for the plant-specific and scenario-specific influences on human performance, particularly including the effects of fires (1 SR)

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Post-Fire HRA – Qualitative Analysis

Slide 9

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Tools for Performing Qualitative Analysis in NUREG-1921

- Information collection and interpretation
- Feasibility assessment
- Development of HFE narrative
- Review of relevant historical experience
- Reviews with plant operations

Tools for Performing Qualitative Analysis – Information collection and interpretation

- Qualitative analysis consists of:
  - Collection and review of "objective" information, e.g.,
    - PRA logic model and its events
    - Data on timing of cues and time available for actions
  - Development of assumptions and assessments of gathered information to explain operator behavior (i.e., interpretation)
  - Development of inputs for HRA quantification methods, e.g.,
    - Performance shaping factors
    - Timing information
    - Other contextual information

Tools … – Information collection and interpretation (continued)

- For fire HRA, three general sources of information:
  1. PRA information needed to understand HFE context, e.g.,
     - PRA model (fire-induced initiating events, event trees, etc.)
     - Success criteria and timing information (from T-H analyses)
     - Other deterministic analysis (e.g., circuit analysis, fire growth)
  2. Plant information needed to understand "as-built, as-operated" plant response and required operator response, e.g.,
     - Procedures (EOPs, fire response procedures, alarm procedures)
     - Alarms and instrumentation that serve as cues for operator actions
     - Plant layout and locations for local operator actions
     - Plant staffing and roles
  3. HRA-specific information, e.g.,
     - Internal events HRA (qualitative analysis and quantification)
     - Interview notes from discussions and talk-throughs
     - Simulator observations, walk-through data, job performance measures

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis
Slide 12
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Tools … – Information collection and interpretation (continued)

- The amount of effort and detail needed from qualitative HRA tasks varies with the fire PRA context
- In turn, the fire PRA context typically varies in detail with NUREG/CR-6850 [EPRI 1011989] Task
  - Task 7a – Screening HEPs often use qualitative information developed during the Identification and Definition HRA task
  - Task 12 – Scoping HRA often uses qualitative information (context and PSF) associated with the scoping HRA trees
  - Task 14 – For risk significant HFEs, perform detailed HRA using qualitative context and PSFs associated with the detailed quantification method

Corresponding PRA Standard SRs: Part 2, HR-F2 and Part 4, HRA–B2

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis
Slide 13
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Tools for Performing Qualitative Analysis - Feasibility assessment

- Feasibility assessments evaluate whether actions associated with HFEs are "feasible," i.e.,
  - capable of being done or carried out
  - per NUREG-1852, a feasible operator manual action is one "that is analyzed and demonstrated as being able to be performed within an available time so as to avoid a defined undesirable outcome"
- Feasibility assessments are needed in fire HRA/PRA for operator actions associated with:
  - All new HFEs (especially for those actions outside the control room)
  - HFEs from existing internal events PRA that are significantly changed in fire context
- Why?
  - Actions often have not been demonstrated, either at all or in fire contexts
  - Actions usually have not been validated by decades of simulator training exercises and vendor testing (as have most actions represented in EOPs and internal events PRAs)

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis

Slide 14

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Tools … - Feasibility Assessment

- The evaluation of feasibility is continuous throughout all fire HRA tasks, i.e.,
  - considered part of **Qualitative Analysis** step
  - begins at the **Identification and Definition** HRA step
  - continues through **Quantification** step
- Feasibility assessments may need to be re-visited as further information becomes necessary and available
- Once feasibility assessments are "complete" in HRA quantification, some of the same factors considered in **feasibility** are re-considered from the **reliability** (or failure probability) perspective

Corresponding PRA Standard SRs: Part 2, HR-G3 to HR-G5; Part 4, HRA-C1

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis

Slide 15

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Tools … - Feasibility Assessment

- Feasibility assessment factors:
  - Sufficient time
  - Sufficient manpower
  - Primary cues available/sufficient
  - Proceduralized and trained
  - Accessible location
  - Equipment and tools available and accessible
  - Relevant components are operable
- Any one of these factors could provide sufficient information to determine whether or not an operator action is feasible, but recommend considering collectively
- NUREG-1921, Section 4.3.4 provides substantial guidance on performing feasibility assessments

Tools … - Feasibility Assessment

- Example guidance for feasibility assessment factors:
  - Sufficient time (and more time may be needed than for internal events HRA due to fire effects) (Sections 4.3.4.1 and 4.6.2)
    - Timeline used to model operator performance
    - Sources of timing information (e.g., job performance measures [JPMs], training exercises, Appendix R feasibility demonstrations)
  - Sufficient manpower (both inside and outside control room)
  - Primary cues available/sufficient (e.g., is a fire impact?)
  - Proceduralized and trained (plus certain *skill-of-the-craft* actions)
  - Accessible location (both travel path and action location; effects of environmental and security measures must be considered)
  - Equipment and tools available and accessible, e.g.,
    - Keys for locked doors
    - Radios, ladders, flashlights, protective clothing, SCBAs

Tools … - Initial Feasibility Assessments

- In Identification and Definition HRA step (see Section 3.5), feasibility assessment is a "Go/No Go" check
  - Ensures that fire PRA is not crediting an operator action that may not be possible
  - If operator action is not feasible, HEP should be set to 1.0
- At this stage, the answers to the following questions <u>may be</u> known:
  - Is there sufficient time to complete action?
  - Are there sufficient cues available for diagnosis?
  - Is the location for the action accessible?
  - Is there enough staff available to complete the action?
  - Has the fire impacted equipment such that the action cannot be performed?
- This initial feasibility assessment is likely to be represented in screening quantification

Tools… - Feasibility Assessments for Scoping and Detailed Fire HRA quantification

- At later stages in fire HRA/PRA, additional information (fire modeling or fire PRA model sequence information) will be available, allowing feasibility assessments to be revised
- Feasibility assessments during scoping and detailed HRA quantification typically examine further details regarding the action, context, scenario and timing
- Especially to support detailed HRA quantification, feasibility assessments are best evaluated through, e.g.,
  - reliable existing information
  - structured interviews
  - if possible, walkthroughs with operations and training personnel
  - photo-documentation of locations to be accessed, equipment to be actuated and tools to be used

Tools for Performing Qualitative Analysis - Development of HFE narrative

- Best way to communicate what is understood about an HFE and its associated PRA scenario is:
  - HFE narrative (or "operational story")
  - An HFE narrative integrates and relates elements of PRA context to other information (e.g., PSFs) as a way to understand plant response and how it relates to operator response
- Elements of HFE narrative for fire HRA:
  - Fire-induced initiating event
  - Accident sequence (including preceding failures and successes)
  - Timing information
  - Accident-specific procedural guidance
  - Cues for operator action and other associated indications
  - Preceding operator errors or successes
  - Operator action success criteria
  - Physical environment

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis

Slide 20

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Tools for Performing Qualitative Analysis - Review of relevant historical experience

- Performed to gain a better understanding of plant and operator response following an event
- Includes both plant-specific and industry-wide incidents (e.g., NRC Information Notices) with focus on contexts in which accidents and operator failures occur
- Usually focuses on a specific type or class of initiating event (e.g., fire or small LOCA)
- May reveal potential influences on operator performance (e.g., plant conditions and associated gaps in procedures or training) and challenging conditions or situations the operators might encounter
- Is particularly relevant to detailed HRA (when more specifics on context are needed) but useful earlier in HRA (e.g., screening), too

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis

Slide 21

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Tools for Performing Qualitative Analysis - Reviews with plant operations

- Typically, several interviews of plant operations personnel are needed to confirm an understanding of plant and operator response
- Early in HRA, first interview(s) used to confirm general understanding (e.g., staffing, procedural hierarchy, communication protocols, how fire procedures are implemented, interactions with fire brigade)
- Later, additional interviews used to review and confirm understanding and modeling of HFEs, e.g.,
  - Specific procedural usage for each action
  - Scenario and plant specific timing information
  - Expected operator response and travel path for specific scenario
- Interviews and plant-specific data collection include plant walk-throughs, talk-throughs, and simulator observations

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis
Slide 22
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Tools … - Reviews with plant operations (continued)

- Tips on conducting talk-throughs:
  - Operators, trainers, and other knowledgeable plant staff should be involved to extent possible
  - Thorough task breakdown is needed to make actions and locations clear
  - Applicable procedures and key indicators need to be identified
  - Feasibility factors (listed previously) should be discussed
  - Thoroughly discuss actions and likely impacts on operator performance
  - Expert elicitation process in ATHEANA User's Guide (NUREG-1880) can be used to assist in developing timing estimates
- Tips on conducting walk-throughs:
  - Set up walk-through to be as realistic as possible
  - Be aware of execution of actions and influencing factors that cannot be represented (e.g., heat or smoke from fire, locations or travel paths that are not accessible while at power)
  - Be aware of factors that can influence timing of actions and range of possible performance times (even if only one demonstration is made)

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis
Slide 23
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Qualitative Analysis – Operator performance influencing factors and special topics

- Operator performance influencing factors:
  - Performance shaping factors for fire context
  - Other relevant contextual factors
- Special topics (and potential areas for additional, future development):
  - Treatment of main control room abandonment
  - Preemptive procedures
  - Operator responses to spurious operations

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis

Slide 24

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Performance Shaping Factors (PSFs)

PSFs are those factors which can impact operator performance (no new categories for fire), e.g.,

- Cues and indications
- Timing (time required and time available)
- Procedures and training
- Complexity
- Workload, stress, pressure
- Human-machine interface
- Environment
- Special equipment
- Crew communication, staffing and dynamics

Corresponding PRA Standard SRs: Part 2, HR-G3 to G5; Part 4, HRA–C1 Note 1

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis

Slide 25

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

PSFs: Cues and Indications

- Cues are the prompts to initiate actions
  - Alarms, indications, and/or procedure steps
- Need to evaluate availability of cues given the fire impact
  - Verify (by cable tracing if necessary) that either
    - (1) Instrumentation is not affected by fire, or
    - (2) It is known that required instrumentation is sufficiently protected and is identified (e.g., procedurally) as such
  - If primary cues or indications are impacted, identify diverse cues and indications that could be credited
    - From the procedure
    - From discussions with plant operators
- If no cue credit can be given, need to quantify HFE with 1.0 or hard-wire operator failure given instrument failure in model

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis
Slide 26
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

PSFs: Timing

- Obtain the following timing for each HFE
  - Total time available (thermal-hydraulic data), e.g.,
    - Time to damage (core damage or component damage)
    - This is usually assessed with a bounding calculation that can be applied in many situations
  - Time that plant response cue occurs relative to the initiating event (thermal-hydraulic data)
  - Time it takes operators to formulate a response (cognitive)
    - Detection, diagnosis and decision-making
    - Data from operator interviews, generic simulator data or observations
  - Time it takes to execute response, given a fire
    - Includes travel, equipment/tools, and manipulation
    - Data from operator interviews, JPMs, training records or observations

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis
Slide 27
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

PSFs: Procedures and Training

- Identify how operators implement fire procedures
  - Implemented in parallel or after completion of EOPs
  - Unlike EOPs, fire procedures might not be standardized or their use could be discretionary
  - Might require more judgmental, rather than "automatic," decisions/actions due to dynamic nature of fires
- Identify critical procedure steps for both cognition and execution
- Identify if and how often operators are trained on both fire procedures and EOPs

PSFs: Complexity

- For local and MCR abandonment actions, the crew may be required to visit various locations
  - As the number of locations increases, the complexity of the situation also increases
  - Multiple actions may require coordination among crew(s), which may increase complexity
  - The number and complexity of the actions and the availability of needed communication devices should be addressed

PSFs: Workload, Pressure and Stress

- For HRA methods that categorize stress into different levels, such as low, moderate and high, a further increase in the level of stress may be considered for fire HRA
- Example - the scenario may be unfamiliar, the procedures and training for the fire scenario may only be considered adequate, the time available to complete the action may be shortened due to fire, and/or the time required may be longer
  - The analyst may therefore decide that stress will have a significant impact on performance, where it may not have been as significant in the internal events HRA

PSFs: Human Machine Interface

- For control room abandonment actions, the adequacy of the remote shutdown and local panels needs to be verified
  - Remote shutdown panels are plant specific and design reviews and improvements have not always been completed
  - Remote shutdown panels are typically not designed for mitigation of all initiating events
  - Additionally, the operators may not be as familiar with the panel layout as they are in control room scenarios
- Local actions that require the use of equipment that has been damaged such that manipulation could be difficult or unlikely to succeed should not be credited in the PRA
  - For example, a hot short on a control cable has caused a valve to close and drive beyond its seat, possibly making it impossible to open manually

PSFs: Environment

- For local actions, there is the potential that the fire could impact ideal travel path to locations. Less direct routes and longer travel times need to be considered
- For control room actions, even if fire does not directly impact control room, environmental conditions outside the control room may still impact operator performance inside the control room (i.e. smoke entering CR from HVAC system)
- For main control room abandonment, actions may need to consider operators' use of SCBA gear
  - Consider effects of smoke, heat and toxic gas for main control room abandonment
    - NUREG/CR-6850 [EPRI 1011989] Section 11.5 provides guidance for impact of smoke

PSFs: Environmental Effects on Feasibility

- Radiation
  - Fire could damage equipment in a way that radiation exposure could be an issue in the location in which the action needs to be taken, causing the need to don personnel protection clothing (extra time)
- Smoke and toxic gas effects
- Increased noise levels from fire fighting activities, operation of suppression equipment, or personnel shouting instructions
- Water on the floor, possibly delaying the actions
- Obstruction from charged fire hoses or large wheeled portable extinguishers
- Heat stress which requires special equipment, limiting time in the area and other precautions; or too many people (getting in each others' way)

PSFs: Special Equipment

- Due to varying environmental conditions during a fire, the crew may require the use of special equipment such as:
  - Keys
  - Ladders
  - Hoses
  - Flashlights
  - Clothing to enter containment areas
- Tools need to be checked to ensure they can be located and accessed during a fire, and that they will likely be functional
- Lists/locations of tools may be cited in procedures
- Pre-job briefings may review use of special equipment

PSFs: Crew Communication, Staffing and Dynamics

- Per NUREG/CR-6850 [EPRI 1011989], most plants can be operated from the control room with two or three operators as the minimum, but a crew may consist of four or five licensed operators
  - thus assigning one to the fire brigade usually does not diminish the control room capability below what is required
- Crew credited for recovery in internal events may no longer be applicable for fire
- For MCR abandonment actions, verify that there are adequate control room members necessary to fulfill the needs of proper shutdown actions from remote shutdown panel (RSP)
- MCR abandonment actions as well as some local actions may require the use of SCBA and could impact communications

Other relevant context factors … that could impact MCR crew

- MCR staff actions can influence the time to respond; such as the time to
  - obtain the correct fire plan and procedures once the fire location is confirmed
  - inform the plant staff of the fire and call for fire brigade assembly and actions
  - alert and/or communicate with local staff responsible for completing various actions
  - provide any specific instructions to the responsible local staff for the actions

Other relevant context factors … that could impact local crew

- Timing considerations of local staff actions can influence the time to respond; such as the time to
  - collect any procedures, establish communications, obtain needed special tools or don personnel protective equipment (PPE)
  - perform preparatory actions such as donning SCBA or personnel protective clothing
  - travel to the necessary locations
  - implement the desired actions; if more than one action they may have to be coordinated or done sequentially
  - inform MCR staff and others that the actions have been successfully completed and the desired effect achieved

Other relevant context factors … crew to crew variability

- Physical size, strength and dexterity differences that may be important for performing the actions
- Cognitive differences (e.g., memory ability, analytic skills)
- Different emotional responses to the fire/smoke
- Different responses to wearing SCBA to accomplish a task (i.e., some people may be more uncomfortable than others with a mask over their faces, thus affecting action times)
- Differences in individual sensitivities to "real-time" pressure
- If the action has training, it is typically assumed that all crew members could complete the action, and crew to crew variability is treated as a sensitivity.

Qualitative Analysis Summary

- Regardless of the HRA quantification method, qualitative information is needed to support evaluation.
  - Provides the data "foundation" used in each Fire HRA process step
  - Objective information, called the FPRA context
  - Evaluated information, such as performance shaping factors (PSFs)
- All PSFs addressed in Part 2 of the ASME/ANS standard (high-level requirements HR-F and HR-G) need to be considered, but may or may not be explicitly used during quantification
- **Qualitative analysis includes**:
  1. Information collection and interpretation (especially for fire-specific context)
  2. Evaluation of HFE feasibility
  3. Development of HFE narrative (or operational story)
  4. Review of historical experience
  5. Review of plant operations
  6. Identification of PSFs and other contextual factors for fire-specific HRA/PRA

Qualitative Analysis – Special topics

- Treatment of main control room abandonment (Section 4.8)
  - NUREG-1921 assumes that MCR will be completely abandoned only if it is uninhabitable
  - NUREG-1921 does not provide detailed guidance on evaluating the decision to abandon the MCR
- Preemptive procedures (Section 4.9)
  - Discussion of issues is provided on preemptive procedures, especially those used by plants that use a self-induced station blackout (SISBO) strategy for addressing fire events
  - NUREG-1921 does not provide any further explicit guidance on modeling or quantifying actions associated with these strategies

Qualitative Analysis – Special topics (continued)

- Operator responses to spurious operations (Section 4.10)
  - NUREG-1921 written to Capability Category II with respect to spurious indications that could affect operator response
  - Section 2.5 discusses how fire PRA (overall) addresses issue of multiple spurious actuations
  - Section 4.10:
    - discusses how spurious indications or actuations of equipment that are not explicitly modeled by fire HRA/PRA could affect operator response
    - provides suggested strategies on how to represent such potential operator behavior through sensitivity studies or uncertainty analysis

EXAMPLES

1. FIRE SPECIFIC CONTEXT DEFINITION
2. CUES AND INDICATION CONFIRMATION
3. PROCEDURES AND TRAINING
4. TIMING

Example of Fire Specific Context Definition

Description: Locally open valve (8804A) for high pressure recirculation following a spurious PORV LOCA

1. Initial Conditions: Steady state, full power
2. Initiating Event:
   - Fire in Area 5A2
   - The fire starts in transformer and impacts targets in the plume and vertical trays adjacent to the flames
   - PORV spuriously opens resulting in small LOCA
3. Accident sequence (functional failures and successes):
   - Reactor trip, Turbine trip
   - No ATWS
   - No containment spray required
   - AFW successful
   - SI actuates due to open PORV
   - Cooldown and depressurization required
   - Switch over to recirculation required

Example of Fire Specific Context Definition

(Continued)

4. Preceding operator error or success in sequence:
   - Operators fail to detect spurious PORV opening prior to auto SI actuation
   - Operators controlled ECCS flow to match make-up flow with leakage rate
   - RHR pumps tripped
   - Cooldown and depressurization either failed or failed to be completed before RWST reaches 33%
5. Operator action success criterion:
   - Recognize 8804A cannot be opened from the control room due to fire damage
   - Locally open 8804A located at 73' RHR Access or 100'
6. Timing (Typically determined from MAAP)
   - Time to RWST 33% = 180 minutes
   - Time to RWST 0% = 300 minutes
   - Time required to perform local valve operation = 25 minutes

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis

Slide 44

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example of Fire Specific Context Definition

(Continued)

7. Consequence of failure: Time to drain RWST
8. Availability of Cues and Indications:
   - RCS Pressure decreasing would be the primary cue operators would be focused on for diagnosing stuck open PORV; RCS pressure indicators are not failed by the fire
   - RWST Level indications are not impacted by fire
   - Monitor light boxes: The indicators at the switch would not be available to alert the operators that the valve failed to close but the monitor light boxes would be giving conflicting information and the operators tend to look at both the position switch and the monitor light boxes

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis

Slide 45

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example of Cues and Indication Confirmation

Description: Locally open valve (8804A) for high pressure recirculation following a spurious PORV LOCA

- Operator interview insights
  - The operators stated that it would be obvious that 8804A failed to open when attempted from the control room. In addition to the position switches in the control room, the valve positions are also monitored on monitor light boxes. The cabling for the monitor light boxes are separate from the valve cabling
  - The operators stated that they are aware that switch-over to recirculation is imminent and they will have an operator preview E1.3 (step 13 of E-1 PREVIEW EOP E-1.3, TRANSFER TO COLD LEG RECIRCULATION). They anticipate that the preview will alert the operators to a failed valve.
- Review of cable tracing
  - The RWST level indicators are not failed by the fire
  - RCS pressure indicators are protected per Appendix R requirements and remain available during the fire
  - The indicator switch in the control room is failed by the fire

Procedures and Training Example

Description: Locally open valve (8804A) for high pressure recirculation following a spurious PORV LOCA

Procedures:

Cognitive: ES 1.3 (Transfer to Cold Leg Recirculation) Revision: 26

Step: 8.g. - Check for charging pump (pp or pps) amps, Charging injection flow and SI Pp flow if pps are in operation

Execution: ES 1.3 (Transfer to Cold Leg Recirculation) Revision: 26

Other: Fire Procedure Revision: 21A

Procedure Notes:

By the time switch over to cold leg recirc is required, the operators will also be looking at CP-M-10 (The fire procedure)

The procedure step in CP-M-10 reads:

Manually close 8804A Power will be isolated (by opening 480V MCC feeder breaker 52-1G-58 to preclude spurious operation of 8982A. If 8982A has opened, then locally close valve 8980 after opening its power breaker 52-1F-31

The operators are trained bi-annually on ES 1.3 but they are not specifically trained on ES 1.3 following a fire with various valve failures

Training – For Non Fire Scenario

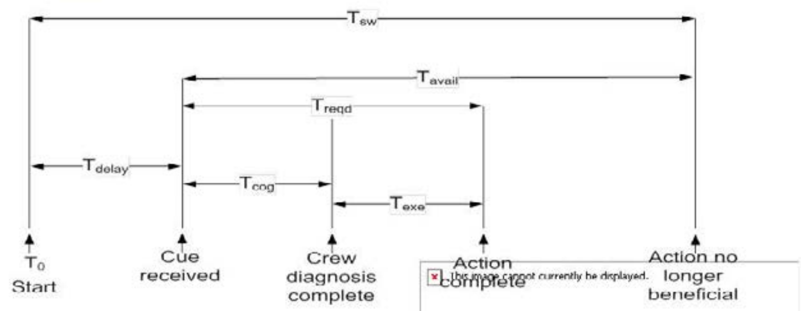
Classroom, Frequency: 0.5 per year

Simulator, Frequency: 0.5 per year

There is no fire specific training for this scenario.

Timing Example

Description: Locally open valve (8804A) for high pressure recirculation following a spurious PORV LOCA



- T_{sw} = 300 min = time to RWST depleted
- T_{delay} = 180 min = switchover to recirc. RWST <33%
- T_{avail} [available Time Window] = 300 -180 = 120 min
- T_{cog} = 2 min = Estimated time to attempt to close CR switch and realize that valve must be closed locally
- T_{exe} = 25 minutes, from operator interviews

Time Margin Calculation

$$\frac{120-(2+25)}{2+25}*100 \sim 360\%$$

Definition and Fire-Specific Context

- HFE Definition starts during Identification with:
  - Cues/alarm or other indications
  - Procedure
  - Staffing
  - Time available
- Feasibility evaluation initially done during Definition, then repeated/updated as HFE is developed
- Fire PRA Context typically varies with NUREG/CR-6850 [EPRI 1011989] Task
  - Task 7a – Screening HEPs often use qualitative info from Definition
  - Task 12 – Scoping HRA often uses qualitative info (context and PSF) associated with the scoping HRA trees
  - Task 14 – For risk significant HFEs, perform Detailed HRA using qualitative context and PSFs associated with the detailed quantification method

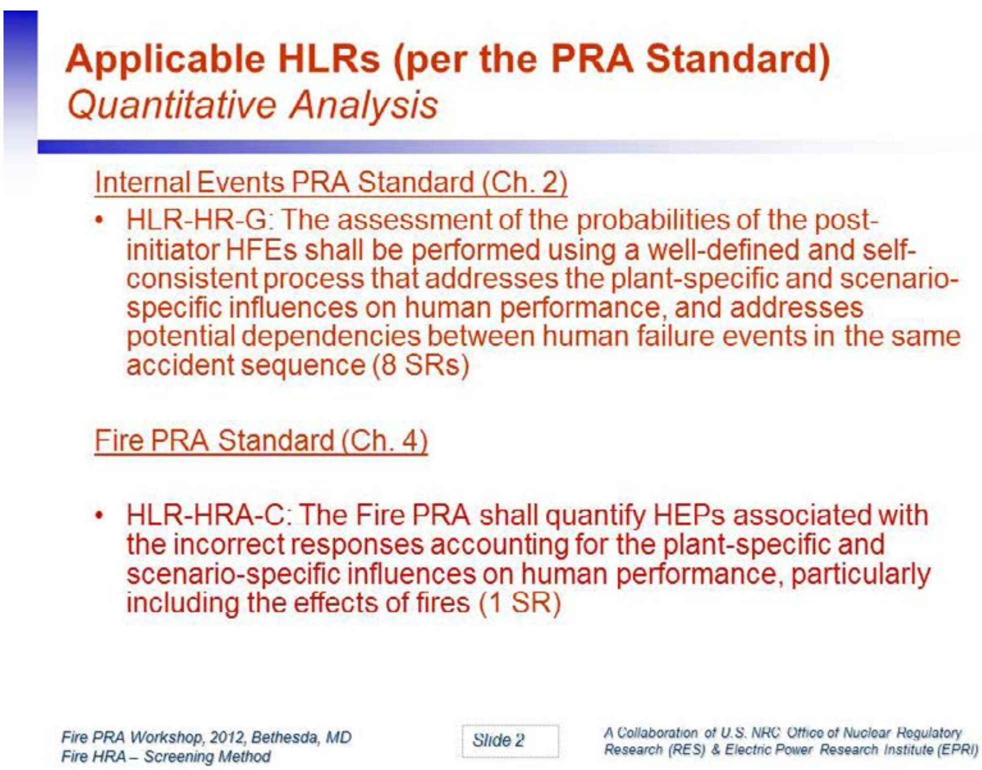
Corresponding PRA Standard SRs: Part 2, HR-F2 and Part 4, HRA–B2

Fire PRA Workshop, 2012, Bethesda, MD
Task 12. Post-Fire HRA – Qualitative Analysis

Slide 50

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

3.4. Screening Quantification



Outline of the Presentation

1. Overview of the EPRI/NRC-RES Fire HRA Guidelines
2. Identification and definition of fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) **Screening**
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

HRA Screening - Fire HRA Objectives

- To verify that reasonable and feasible human actions and associated fire human failure events (HFEs) are
  - Identified and evaluated for fire effects
  - Included in Fire PRA

- To simplify PRA fire model by appropriately assigning screening HEPs for fire induced accident scenarios
  - Establish HEP screening values for developing Fire PRA model
  - Help focus analysis resources on the higher risk sequences

PRA Standard Definitions

- Screening – "a process that eliminates items from further consideration based on their negligible contribution to the probability of an accident or its consequences."
- Screening criteria – "the values and conditions used to determine whether an item is a negligible contributor to the probability of an accident sequence or its consequences."
- Corresponding PRA Standard SRs:
  - Part 2, HR-G1 and
  - Part 4, HRA-C1

Fire HRA Screening Analysis

- Method similar to that presented in NUREG/CR-6850 (EPRI 1011989)
- Supports assignment of screening values by:
  - addressing the key conditions that can influence crew performance during fires,
  - ensuring that the time available to perform the necessary action is appropriately considered (given the other on-going activities in the accident sequence), and
  - evaluating potential dependencies among HFEs modeled in a given accident sequence
- To facilitate simplified level of analysis, HFEs are sorted into "screening sets"

Fire HRA Screening - Inputs

- Mitigating equipment and diagnostic indications
  from Task 2 (Fire PRA Component Selection)
- Human actions carried over from Internal Events PRA
  from Task 5 (Fire-Induced Risk Model development)
- EOPs and fire ~~Emergency~~ procedures ~~(FEPs)~~ - to identify new potentially risk important human actions that support Appendix R assumptions
- Equipment failures, spurious operations and indications; timing and fire location information for feasibility assessment – if available when screening is performed:
  - Task 3 (Fire PRA Cable Selection),
  - Tasks 9 (Detailed Circuit Failure Analysis) & 10 (Circuit Failure Mode Likelihood Analysis)
  - Tasks 8 (Scoping Fire Modeling) and 11 (Detailed Fire Modeling)

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Screening Method
Slide 7
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Screening - Outputs

- May identify other equipment and indications that are needed to carry out a human action for Task 2 (Fire PRA Component Selection)
- May identify HFE modeling additions needed in Task 5 (Fire-Induced Risk Model) to account for pre-emptive procedure-driven actions to avoid fire-induced spurious equipment actuations
- Provide screening HEPs for Task 7 (Quantitative Screening)
- Identify HFEs requiring additional analysis (scoping or detailed)

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Screening Method
Slide 8
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Screening - Screening Criteria Sets

- NUREG/CR-6850 (EPRI 1011989) screening criteria produced HEPs for longer term actions (>1 hour after fire initiation and plant trip) that were overly conservative, even for screening, so this has been modified
- Criteria summary:
  - Set 1: Internal events PRA HFEs that are only indirectly affected by the fire scenario
  - Set 2: Internal events HFEs that have added complications from spurious actuations
  - Set 3:
    - new fire-related HFEs
    - HFEs modeled in internal events PRA that need to be significantly revised to reflect fire effects
  - Set 4: HFEs associated with Alternative Shutdown (including MCR Abandonment)

Fire HRA Screening Criteria: Set 1 Existing Level 1 internal events PRA HFEs

- Plant trip with no significant damage to safe shutdown equipment or related instrumentation beyond internal events PRA
- No spurious cues or equipment actuations for safety-related equipment
- Necessary immediate responses are not attributed to fire
- One train/division of safe shutdown-related equipment and instrumentation is completely protected from fire
- MCR crew responsible for safe shutdown have no significant additional responsibilities

Fire HRA Screening Criteria: Set 1 (continued)

- No significant environmental impact or threat to MCR crew (e.g., smoke)
- Time available to diagnose and implement the action(s) is not significantly different than internal events PRA-related scenario(s) where HFE(s) apply
- Ex-MCR manual actions from internal events PRA are not significantly affected by smoke or toxic gases, loss of lighting, radiation threat
- Staff, special tools and communication capability are available to perform ex-MCR actions
- Dependency between multiple HFEs in internal events PRA sequences is still applicable to fire PRA

Fire HRA Screening Criteria: Set 2
Modification to existing HFEs for spurious effects

- Set 2 screening criteria same as Set 1, except when
  - Significant spurious electrical effects are likely occurring in one (and only one) safety-related train/division of equipment and/or instrumentation important to the critical safety functions
- Presumes that some corrective responses on the part of the crew may be needed
- In Set 2, the crew might have to attend and respond to the spurious activity in the affected train/division to make sure it does not affect their ability to reach safe shutdown (e.g., causing a diversion of all injection).
- However, the crew would likely detect the spurious activity quickly and not be confused by it
- The Set 2 screening adjustments are intended to conservatively bound the general fire effects on Set 1 internal events PRA actions. Set 2 adjustments do not address operator actions added to the PRA model to address additional fire scenario concerns.

Fire HRA Screening Criteria: Set 3
New or significantly modified HFEs

- These criteria address
  - new HFEs added to the fire PRA or
  - prior internal events PRA HFEs needing to be significantly altered or modified because of fire conditions
- In such cases, pre-existing internal events PRA HEPs either do not exist, or are not appropriate as a basis for the fire PRA
- If action is within 1st hour of fire initiation, set HEP to 1.0 for screening
- If action is long term, apply 0.1 or 10 times internal events PRA HEP, whichever is lower

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Screening Method

Slide 13

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Screening Criteria: Set 4
Alternative Shutdown HFEs

- All HFEs involved in reaching safe shutdown from outside the MCR, including HFEs representing the decision to abandon the MCR, should be assigned screening values of 1.0 since more detailed analysis is needed
- As discussed in Section 11.5.2.10 of NUREG/CR-6850 (EPRI 1011989), an overall probability value (often, 0.1) to represent the failure of reaching safe shutdown using alternate means can be used if the value is evaluated conservatively and a proper basis is provided
  - this approach was used in several IPEEE submittals
  - may be sufficient when MCR abandonment is proven to not be risk-significant
  - before crediting this approach, apply the criteria discussed in NUREG-1921
    - Section 4.3 for feasibility assessment
    - Section 4.8 for MCR abandonment qualitative analysis

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Screening Method

Slide 14

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire HRA Screening - Basis for Screening Values

- Conservative HEP values have no direct empirical basis
- Qualitative basis comes from experience with
  - Range of screening values used and accepted in HRA
  - Quantifying HEPs for events in nuclear power plant HRAs
  - Applying range of HRA methods and values associated with those methods
  - Performing HRA for fire PRAs, including pilots
- Other inputs
  - Peer review comments
  - Not so low so as to miss potential dependencies among HFEs

Fire HRA Screening - Quantification

- Assign screening HEPs on a fire scenario specific basis
- Four sets of screening criteria :
  - Set 1 (existing Level 1 HFEs): Multiply internal events HEP by 10 to account for effects of potential fire brigade interaction and other minor increased workload/distraction issues. Examine dependencies across scenario
  - Set 2 (modification to existing HFEs re: spurious events): Spurious events impact one critical safety-related train/division: increase internal events HEP to 0.1, or 10 times original value, whichever is greater. Examine dependencies across scenario
  - Set 3 (new or significantly modified HFEs): Applies to new HFEs and existing HFEs not meeting Set 1 or 2. Use 1.0 if action has to be performed within one hour of fire initiation. Use 0.1, or 10 times existing HEP, if > 1 hour, whichever is lower (relaxation of original screening guidance)
  - Set 4 (alternative shutdown HFEs): Use screening value of 1.0 or use overall value of 0.1 with documented justification (relaxation of original screening guidance)

Quantitative Screening Summary

Screening Criteria	Short-Term Human Actions: Definition	Short-Term Human Actions: Value	Long-Term Human Actions: Definition	Long-Term Human Actions: Value
Set 1: similar to internal events HFE but with some fire effects	Required within first hour of fire/trip	10x internal events HEP	Performed ~1 hour after fire/trip (fire effects no longer dynamic, equipment damage understood, and fire does not significantly affect ability of operators to perform action)	Same as internal events HEP
Set 2: similar to Set 1 but with spurious equipment or instrumentation effects in one safety-related train/division		0.1, or 10x internal events HEP, whichever is greater		0.1, or 10x internal events HEP, whichever is smaller
Set 3: new fire HFEs or prior internal events HFEs needing to be significantly modified as a result of fire conditions		1.0		0.1, or 10x internal events HEP, whichever is smaller
Set 4: alternate shutdown (including MCR abandonment)	1.0 for initial screening (per Section 5.1.1.4), or 0.1 following feasibility assessment (per Section 4.3) and qualitative analysis (per Section 4.8)			

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) **Screening**
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

3.5. Screening Examples

SCREENING EXAMPLES

Fire PRA Workshop 2013 - Charlotte, NC
Fire HRA – Screening Analysis Examples

Slide 2

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

General Assumptions for Screening Examples

- Actions have applicable plant emergency procedures and fire procedures
- Limited information is available on fire locations and equipment impacts since fire modeling and circuit analysis are usually still in early stages
- Fire PRA model needs preliminary fire HEPs to test model logic and ensure that HFEs are not lost in the noise
- Fire effects minimized after one hour
- Note: Similar examples are being used to illustrate screening, scoping & detailed approaches, but scenario specifics may not be identical

Fire PRA Workshop 2013 - Charlotte, NC
Fire HRA – Screening Analysis Examples

Slide 3

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Quantitative Screening Approach Summary

Screening Criteria	Short Term Human Actions – Definition	Short Term Human Actions – Value	Long Term Human Actions – Definition	Long Term Human Actions – Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x Internal Events HEP	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as Internal Events HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x Internal Events HEP, whichever is greater		0.1, or 10x Internal Events HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x Internal Events HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown			

Example 1: Operator fails to switch turbine building SW header

- While in an at power condition with normal alignment of Service Water, a low Service Water pressure condition develops. At the same time fire causes a reactor trip
- Annunciators activate and Service Water pressure indicates less than 72 psig
- Operator fails to respond per appropriate ARP and swap the turbine building SW header selector switch to the opposite header

Example 1:
Operator fails to switch turbine building SW header

- MCR action
- Short term available timeframe (14 minutes) according to Internal Events HRA
- Time for implementing action:
  - Diagnosis time = 4 minutes
  - Execution time = 1 minute
- Internal Events HEP using HCR/ORE/THERP in EPRI HRA Calculator = 1.7E-03
- Similar to Internal Events situation, but some potential fire effects

Example 1:
Screening Selection Criteria

1. Operator Action timeframe
   - ➡ Short (<1 hour)
   - Long (> 1 hour)
2. Spurious Instrumentation/Equipment effects in one safety-related train
   - Yes
   - ➡ No
3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   - Yes
   - ➡ No

Example 1: Quantitative Screening Summary

Screening Criteria	Short Term Human Actions		Long Term Human Actions	
	Definition	Value	Definition	Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x Internal Events HEP 1.7E-03 * 10 = 1.7E-2	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as Internal Events HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x Internal Events HEP, whichever is greater		0.1, or 10x Internal Events HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x Internal Events HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown			

Example 2: Operator fails to align FPS water to AFW pumps

- The auxiliary feedwater pumps take water from the auxiliary feedwater storage tank.
- With low low level in the tank, the operator would align the FPS (fire protection system) to the pumps.
- Consider the tank low low level (10%) would be reached in 10 hours. At this level the operator will receive an alarm (sound and light)
- The operator has to open manual valves. (At least one valve)
- At 10% low low level the local operator must align the FPS.
- Operator has 1 hour before loss of cooling from low low level cue

Example 2:
Operator fails to align FPS water to AFW pumps

- Local action
- Cable tracing for AFWST level transmitters <u>has</u> been performed and the cues are not impacted by fire
- Long term action (10 hours)
- Time available is large (60 minutes)
- Time for carrying out action:
  - Diagnosis time = 2 minutes
  - Execution time = 10 minutes

Example 2:
Screening Selection Criteria

1. Operator Action timeframe
   - Short (<1 hour)
   - ➡ Long (> 1 hour)
2. Spurious Instrumentation/Equipment effects in one safety-related train
   - Yes
   - ➡ No
3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   - Yes
   - ➡ No

Example 2: Quantitative Screening Summary

Screening Criteria	Short Term Human Actions		Long Term Human Actions	
	Definition	Value	Definition	Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x Internal Events HEP	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as Internal Events HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x Internal Events HEP, whichever is greater		0.1, or 10x Internal Events HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x Internal Events HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown			

Example 3: Operator fails to align FPS water to AFW pumps with failed alarm

- Same basic scenario as Example 2
  - The auxiliary feedwater pumps take water from the auxiliary feedwater storage tank (AFWST).
  - When low low level in the tank is reached, the operator needs to align the FPS (fire protection system) to the pumps.
- Cable tracing has not been done therefore assume that fire fails the AFWST alarm at the 10% level
  - spurious indication assumed
- Fire procedures direct operator to check tank level locally and consider refilling if needed
  - Diagnosis time is increased

Example 3:
Operator fails to align FPS water to AFW pumps with failed alarm

- Local action
- Long term action (10 hours)
- Time available is large (60 minutes)
- Time for carrying out action:
  - Diagnosis time = 15 minutes
  - Execution time = 10 minutes

Example 3:
Screening Selection Criteria

1. Operator Action timeframe
   - Short (<1 hour)
   - ➔ Long (> 1 hour)
2. Spurious Instrumentation/Equipment effects in one safety-related train
   - ➔ Yes
   - No
3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   - Yes
   - ➔ No

Example 3: Quantitative Screening Summary

Screening Criteria	Short Term Human Actions – Definition	Short Term Human Actions – Value	Long Term Human Actions – Definition	Long Term Human Actions – Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x Internal Events HEP	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as Internal Events HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x Internal Events HEP, whichever is greater		0.1, or 10x Internal Events HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x Internal Events HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown			

Fire PRA Workshop 2013 - Charlotte, NC
Fire HRA – Screening Analysis Examples
Slide 16
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 4: Operator fails to initiate bleed & feed and use of fire procedures

- The action to initiate bleed and feed will be done when the SGs are almost in dry out
- Cue to initiate bleed and feed is when 2 SGs are at less than 15% WR level
- In this case half of the indicators of SG level are failed and fire procedures must be used to identify which indicators are accurate
- With the main feedwater and auxiliary feedwater systems unavailable at the beginning of the initiating event, the SG goes to dry out in 45 minutes

Fire PRA Workshop 2013 - Charlotte, NC
Fire HRA – Screening Analysis Examples
Slide 17
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 4:
Operator fails to initiate bleed & feed and use of fire procedures

- MCR action
- Total system time window = 45 minutes for the SGs to dry out
- Time from cue = 25 minutes
- Time for carrying out action:
  - Diagnosis time = 8 minutes [additional time than standard bleed & feed due to using multiple procedures]
  - Execution time = 8 minutes

Fire PRA Workshop 2013 - Charlotte, NC
Fire HRA – Screening Analysis Examples

Slide 18

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 4:
Screening Selection Criteria

1. Operator Action timeframe
   - → Short (<1 hour)
   - Long (> 1 hour)
2. Spurious Instrumentation/Equipment effects in one safety-related train
   - Yes
   - → No
3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   - → Yes Simultaneous use of multiple procedures
   - No

Fire PRA Workshop 2013 - Charlotte, NC
Fire HRA – Screening Analysis Examples

Slide 19

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 4: Quantitative Screening Summary

Screening Criteria	Short Term Human Actions – Definition	Short Term Human Actions – Value	Long Term Human Actions – Definition	Long Term Human Actions – Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x Internal Events HEP	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as Internal Events HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x Internal Events HEP, whichever is greater		0.1, or 10x Internal Events HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x Internal Events HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown			

Example 5: Operator fails to establish containment spray sump recirculation when RWST depleted

- Operator action to align containment spray (CS) to sump recirc when the RWST is depleted
- The operators cue on RWST level <37%, per the foldout page in Procedure E-1 Transition to ES-1.3, Transfer to Containment Sump Recirculation.
- The following assumptions are made:
  - All equipment operates as designed
  - Conditions requiring CS exist

Example 5:
Operator fails to establish containment spray sump recirculation when RWST depleted

- MCR action
- Since CS is needed, fire is presumed to be severe in its consequences
- RWST level indicators have cable tracing and the cues are not impacted by fire
- Total system time window = for the 37% RWST level to have been reached, more than 60 min are assumed to have passed since the reactor trip
- Internal Events HEP using CBDTM/THERP in EPRI HRA Calculator = 3.6E-03

Example 5:
Screening Selection Criteria

1. Operator Action timeframe
   - Short (<1 hour)
   - ➡ Long (> 1 hour)
2. Spurious Instrumentation/Equipment effects in one safety-related train
   - Yes
   - ➡ No Uncertain what multiple effects might occur
3. New Fire HFE or Existing HFE needs to be significantly altered to reflect fire effects
   - ➡ Yes
   - No

Example 5: Quantitative Screening Summary

Screening Criteria	Short Term Human Actions		Long Term Human Actions	
	Definition	Value	Definition	Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x Internal Events HEP	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as Internal Events HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x Internal Events HEP, whichever is greater		0.1, or 10x Internal Events HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x Internal Events HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probabil representing failure to reach safe shutdov			

3.6E-03 * 10 = 3.6E-2

Example 6: Operator fails to maintain control from alternate shutdown location

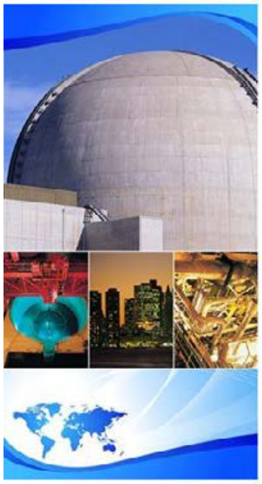
- Multiple MCR and local actions
- Procedures exist but actions require significant coordination and communication among operators
- In such cases, presume detailed analysis will be required if risk-significant in fire PRA model

Example 6: Quantitative Screening Summary

Screening Criteria	Short Term Human Actions		Long Term Human Actions	
	Definition	Value	Definition	Value
Set 1 – like Internal Events HFE, but with some fire effects	Required within first hour of trip/fire	10x Internal Events HEP	Performed ~one hour after fire/trip (fire effects no longer dynamic, equipment damage understood, fire does not significantly affect ability of operators to perform action)	same as Internal Events HEP
Set 2 - like Set 1, but with spurious equipment or instrumentation effects in 1 safety-related train/division		0.1, or 10x Internal Events HEP, whichever is greater		0.1, or 10x Internal Events HEP, whichever is smaller
Set 3 - new fire HFEs or prior IE HFEs needing to be significantly modified due to fire conditions		1		0.1, or 10x Internal Events HEP, whichever is smaller
Set 4 – Alternate Shutdown (including MCR abandonment)	1 for HFE, or 0.1 for single overall probability representing failure to reach safe shutdown			

3.6. <u>Scoping Quantification Approach</u>

Sandia National Laboratories | CURTISS WRIGHT Flow Control Company SCIENTECH | EPRI ELECTRIC POWER RESEARCH INSTITUTE | SAIC Science Applications International Corporation From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY
Task 12 – Fire HRA

Scoping Quantification Approach

Joint NRC-RES/EPRI Fire PRA Workshop 2012
Bethesda, MD

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method
Slide 2
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Three General Approaches to HRA Quantification

- Screening: Slightly modified from NUREG/CR-6850 (EPRI 1011989) to cover late (after fire is out) events
- **Scoping fire HRA quantification approach (new)**
  - Less conservative than screening, but designed to be slightly more conservative than detailed approaches
  - Some actions may not be able to meet some of the criteria (result in an HEP of 1.0)
- Two detailed fire HRA quantification approaches, modified for application in fire scenarios
  - EPRI Cause-Based Decision Tree (CBDT) & HCR/ORE; THERP
  - ATHEANA

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method
Slide 3
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Purpose of Scoping Approach

- Provide less conservative HEPs for HFEs surviving screening
  - Straightforward approach without too much detailed analysis
- Intent is to provide HEPs that are more realistic, and therefore, some detailed analysis required
  - HEPs thought to be somewhat more conservative than might be obtained with more detailed analysis
  - Expected to limit need for detailed analyses for many HEPs
- Relies on assessment of feasibility of actions and a time margin to account for many of the uncertainties associated with fire scenarios (e.g., per NUREG-1852)
- Requires simple judgments about PSFs

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method
Slide 4
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Categories of Actions Addressed in Scoping Flowcharts

- New and existing main control room (MCR) actions
- New and existing ex-control room (local) actions
- Actions associated with using alternate shutdown means
  - due to MCR habitability issues, or
  - due to difficulties in controlling the plant from the MCR because of the effects of the fire
- Recovery of Errors of Commission (EOCs) or Errors of Omission (EOOs) due to spurious instrumentation
  - Supports addressing spurious instrument effects as described in Part 4 (Internal Fires) of ASME/ANS Combined PRA Standard (HLR-ES-C1 and C2)

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 5

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Categories of Actions NOT Addressed in Scoping Flowcharts

- Complex diagnosis should not be addressed with the Scoping Method
  - Simplified approach not appropriate for cognitively complex or challenging scenarios
- Example of cognitively complex or challenging scenarios:
  - Cues directly relevant to the action being modeled do not match the procedural guidance
  - Plants that implement SISBO procedures
  - Actions pertaining to deciding to abandon the MCR*
  - Scenarios that may include potentially distracting spurious operations

*scoping approach may be used to quantify HFEs subsequent to the decision to abandon.

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 6

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Steps for Using Scoping Fire HRA Approach

1. Ensure minimum criteria are met
2. Assess feasibility of operator actions
3. Calculate time margin
4. Assess key conditions and PSFs
5. Use flowcharts to quantify - Search scheme directs to one of the following:
   - INCR = In MCR actions
   - EXCR = ex-MCR actions (actions normally performed locally)
   - ASD = Alternative Shutdown (including MCR Abandonment due to habitability or transferring command and control to outside the MCR due to an inability to control the plant)
   - SPI = recovery of errors due to spurious instrumentation

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 7

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Minimum Criteria

1. Procedures
   - Procedures should match the scenario
   - Plant procedures covering each operator action being modeled should be present
   - Support both diagnosis & execution of the action
   - Exceptions:
     - Execution of skill-of-the-craft actions
     - Recovery of EOO or EOC in some cases related to self- or crew-recovery for inappropriate response to spurious indications

2. Training – on the procedures and the actions

3. Availability and Accessibility of Equipment

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 8

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Assessment of Feasibility

- Feasibility assessments during scoping HRA quantification typically examine further details regarding the action, context, scenario and timing
- Refer to Qualitative Analysis presentation sections on Tools for Feasibility Assessment and conducting Talk- and Walk-throughs, as well as NUREG-1921 sections:
  - **4.3 Feasibility Assessment**
  - **4.11 Reviews with Plant Operations**
- Scoping method effectively implements a feasibility assessment on the basis of time and environmental conditions (dense smoke)

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 9

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Qualitative Assessment Tools … - Feasibility Assessment

- Example guidance for feasibility assessment factors:
  - Sufficient time (Section 4.3.4.1 along with Section 4.6.2 (PSF – Timing))
    - Timeline used to model operator performance
    - Sources of timing information (e.g., job performance measures [JPMs], training exercises, Appendix R feasibility demonstrations)
  - Sufficient manpower (both inside and outside control room)
  - Primary cues available/sufficient (e.g., is a fire impact?)
  - Proceduralized and trained (plus certain *skill-of-the-craft* actions)
  - Accessible location (both travel path and action location; effects of environmental and security measures must be considered)
  - Equipment and tools available and accessible, e.g.,
    - Keys for locked doors
    - Radios, ladders, flashlights, protective clothing, SCBA

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

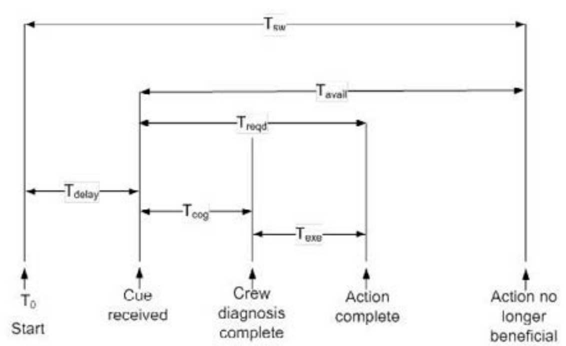
Slide 10

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Time Margin

- Extra time included to account for potential unexpected fire effects and variabilities such as:
  - Uncertainties in the demonstrations and conditions unable to be simulated
  - Potential variability in crew response times and individual differences
  - Variations in fire type and related plant conditions
- Within the scoping approach, time margins are required to be calculated for all actions or set of actions.
- Similar to guidance in NUREG-1852

Calculation of Time Margin



$$Time\ Margin\ (TM) = \frac{T_{AVAIL} - T_{reqd}}{T_{REQD}} * 100\% = \frac{[(T_{sw} - T_{delay}) - (T_{COG} + T_{EXE})]}{(T_{COG} + T_{EXE})} * 100\%$$

Calculation of Time Margin (2)

- Times used should be based on realistic times
- Some actions may involve either (or a mix of both) serial and parallel actions, with overlapping tasks. In these cases, determination of the time margin may not be as straightforward as illustrated. For more guidance, see Appendix A of NUREG-1852.

Calculation of Time Margin (3)

- Range of times should be collected in addition to the point estimate of an average crew
  - Especially important when required time is close to available time
  - Potential uncertainty in timing data important when a small change in the estimated time required could make the action infeasible
- "Tipping Points": a few additional minutes of estimated time results in different HEP in scoping method
  - Recommendation is to initially choose the conservative estimate of time; Refine data later if significantly impacts fire PRA model quantification results
  - Alternative: run several test cases to evaluate the impact of timing variability and quantify the HFE with separate timing cases if the impact is strong enough to warrant it

Assessing Key Conditions & PSFs within the Scoping Flowcharts

- How well the procedures match the scenario
  - The procedures should be relatively easy to follow given the pattern of indications
  - Serves as a proxy for diagnostic complexity
- Response execution complexity
  - Assessed as high or low
  - Complexity is usually considered **low** if:
    - Requires a single step
    - Performed by a single crew member
    - Multiple simple steps performed by single crew members working independently
    - Clear procedures or skill-of-craft
  - Complexity is usually considered **high** if:
    - Multiple steps that may be ambiguous or difficult
    - Multiple crew members performing coordinated steps
    - Multiple location steps if coordination/communication required
    - Multiple functions (e.g., both electrical and mechanical alignment)

Assessing Key Conditions & PSFs within the Scoping Flowcharts (2)

- Timing of cues for the action relative to expected fire suppression time.
  - If fire type unknown, fire suppression assumed to be 70-minutes ("all fires")
  - If fire type is known, may use the 99th %ile value (yellow) from FAQ 08-0050
  - Fire must be considered on-going for the fire types in red

Time (min)	T/G fires	High energy arcing faults	Outdoor transformers	Flammable gas	Oil fires	Electrical fires	Transient fires	PWR containment	Welding	Control Room	Cable fires	All Fires
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	0.883	0.947	0.836	0.881	0.684	0.602	0.531	0.687	0.392	0.189	0.446	0.714
10	0.780	0.897	0.698	0.776	0.468	0.362	0.282	0.472	0.153	0.036	0.199	0.510
15	0.689	0.850	0.584	0.683	0.320	0.218	0.150	0.325	0.060	0.007	0.089	0.364
20	0.609	0.805	0.488	0.602	0.219	0.131	0.080	0.223	0.024	0.001	0.040	0.260
25	0.538	0.762	0.408	0.530	0.150	0.079	0.042	0.153	0.009	*	0.018	0.186
30	0.475	0.722	0.341	0.467	0.102	0.048	0.023	0.105	0.004	*	0.008	0.133
35	0.419	0.684	0.285	0.411	0.070	0.029	0.012	0.072	0.001	*	0.004	0.095
40	0.370	0.647	0.238	0.362	0.048	0.017	0.006	0.050	*	*	0.002	0.068
45	0.327	0.613	0.199	0.319	0.033	0.010	0.003	0.034	*	*	*	0.048
50	0.289	0.581	0.166	0.281	0.022	0.006	0.002	0.024	*	*	*	0.035
55	0.255	0.550	0.139	0.248	0.015	0.004	*	0.016	*	*	*	0.025
60	0.226	0.521	0.116	0.218	0.010	0.002	*	0.011	*	*	*	0.018
65	0.199	0.493	0.097	0.192	0.007	0.001	*	0.008	*	*	*	0.013
70	0.176	0.467	0.081	0.169	0.005	*	*	0.005	*	*	*	0.009
75	0.155	0.443	0.068	0.149	0.003	*	*	0.004	*	*	*	0.006
80	0.137	0.419	0.057	0.131	0.002	*	*	0.002	*	*	*	0.005
85	0.121	0.397	0.047	0.116	0.002	*	*	0.002	*	*	*	0.003
90	0.107	0.376	0.040	0.102	0.001	*	*	0.001	*	*	*	0.002
95	0.095	0.356	0.033	0.090	*	*	*	*	*	*	*	0.002
100	0.084	0.337	0.028	0.079	*	*	*	*	*	*	*	0.001

Assessing Key Conditions & PSFs within the Scoping Flowcharts (3)

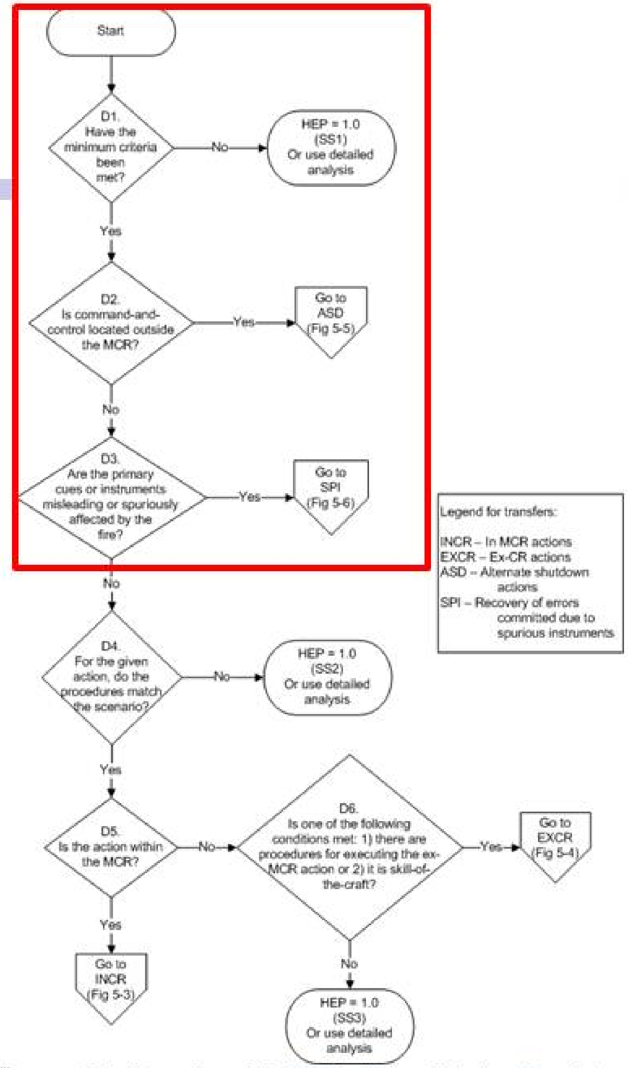
- Action time window
  - Time from the occurrence of the cues for action until the action is no longer beneficial
  - Short time window = 30 minutes or less
  - Long time window = greater than 30 minutes
- Level of smoke and other hazardous elements in the action areas
  - Need for special equipment (e.g., SCBA)
  - Impairment of vision or prevention of the execution of the action
- Accessibility
  - Location of action
  - Travel path

Use of Scoping Flowcharts

- HFEs quantified based on:
  - Assessment of key PSFs
  - Location of the actions associated with the HFE
  - Condition of relevant instrumentation
- A *Search Scheme* directs the analyst to the correct flowchart for quantification:
  - In-MCR action (INCR)
  - Ex-MCR action (EXCR)
  - Alternative Shutdown (ASD)
  - Recovery of error due to spurious instrumentation (SPI)
- Some HFEs quantified within the Search Scheme lead to HEP = 1.0

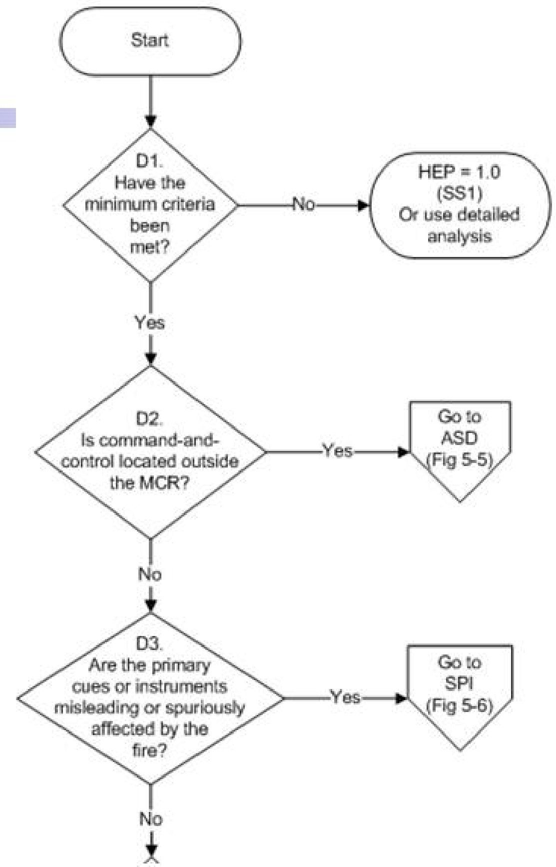
Search Scheme

- Directs analyst to correct quantification flowchart



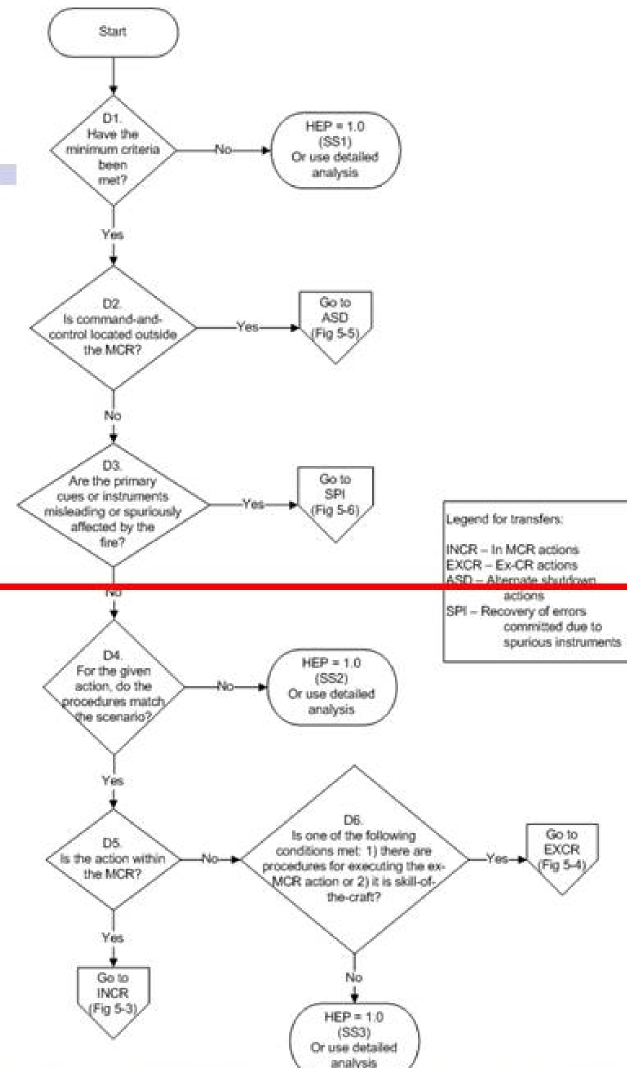
Search Scheme

- Direct to ASD or SPI tree
- Cues are not necessary to answer yes to D1, but likely their absence will still result in HEP = 1.0 later on

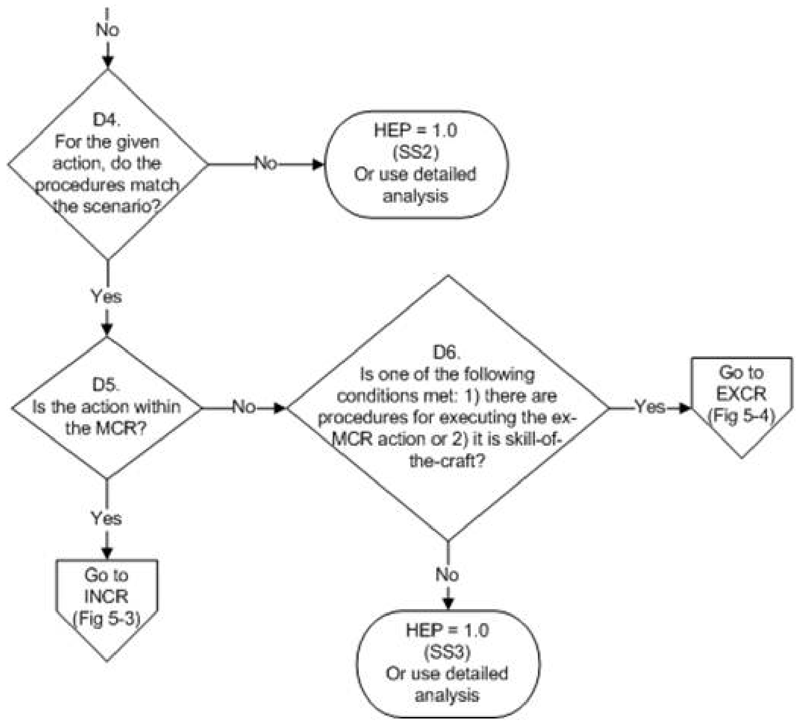


Search Scheme

- Directs analyst to correct quantification flowchart



Search Scheme



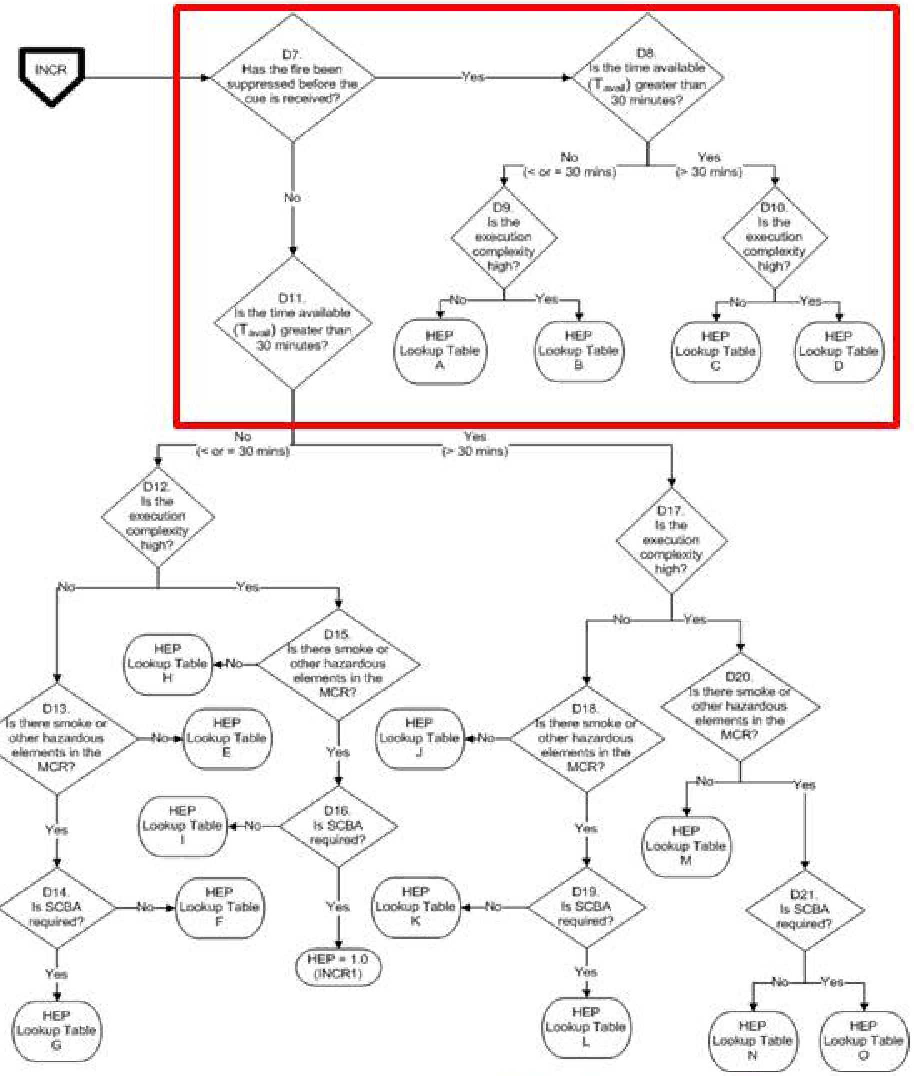
- Direct to INCR or EXCR

INCR – In-MCR Actions

- Used for the following HFEs:
  - New HFEs identified outside the Internal Events PRA
  - Existing HFEs from the Internal Events that survive quantitative screening
- Addresses diagnosis and execution of the action in the MCR
  - Presumes no challenge to MCR habitability or functionality from fire (see ASD)

INCR

- Scoping HRA for in MCR Actions



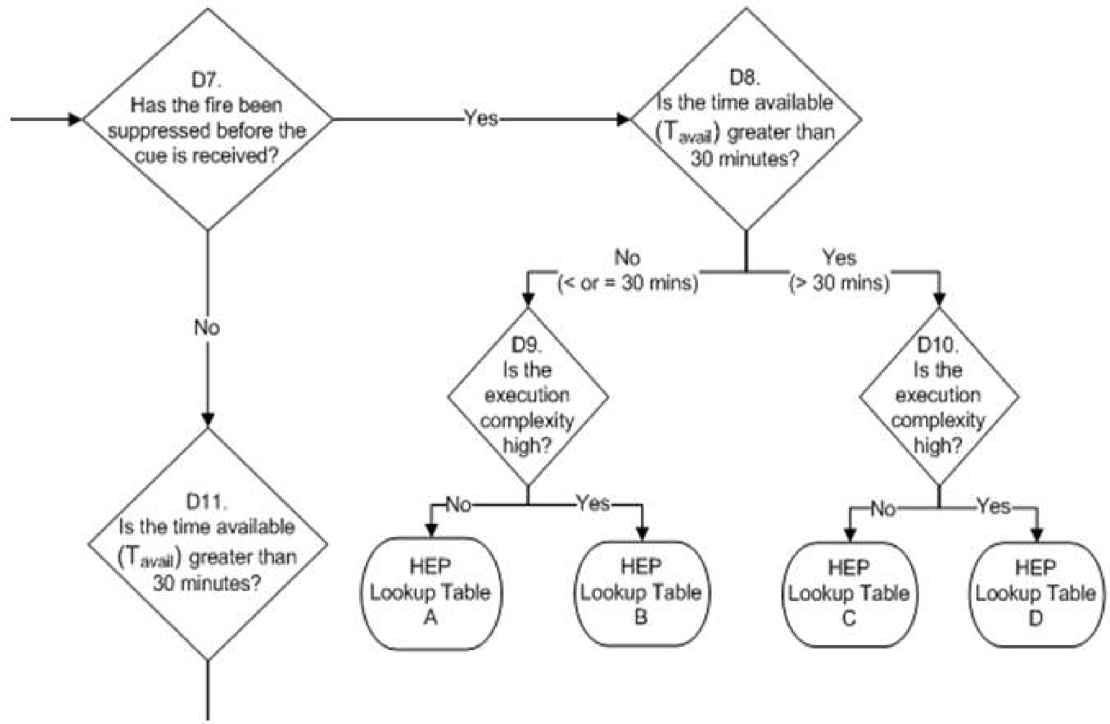
Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 24

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

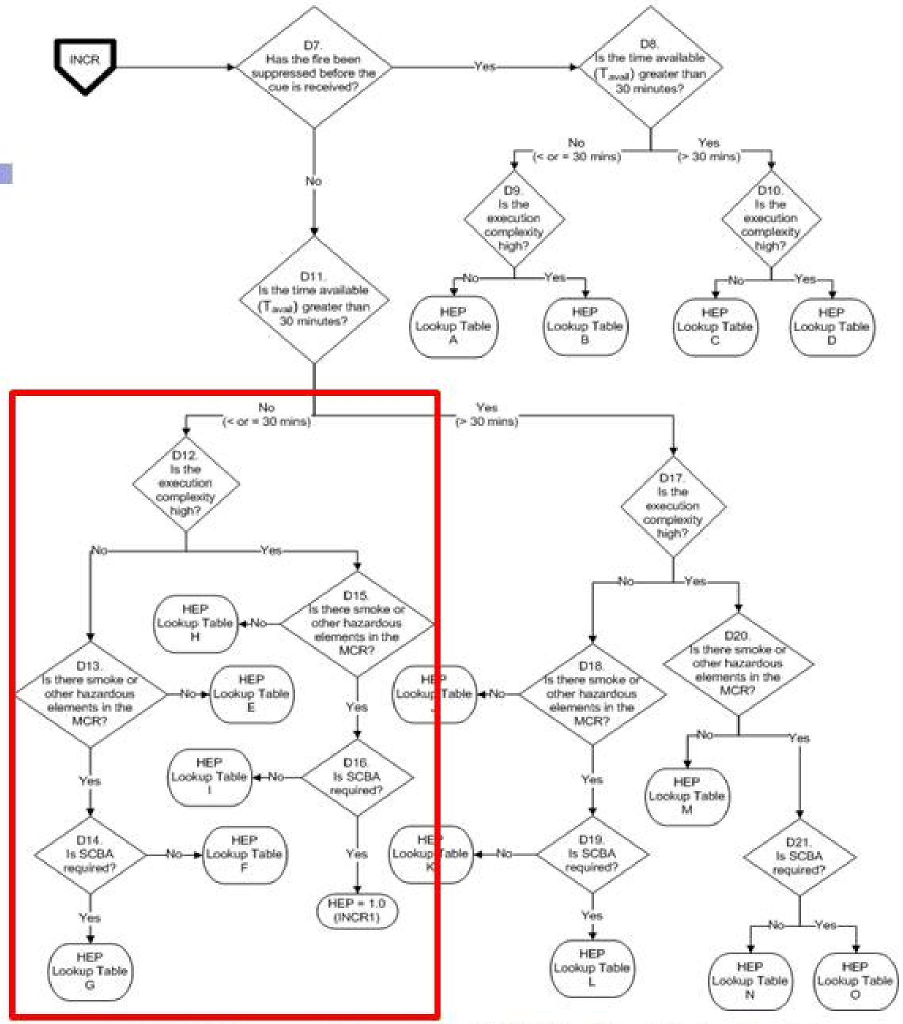
INCR

- Fire Suppressed?
  - 70 minutes from reactor trip
  - Fire specific timing [FAQ-08-0050]
  - Challenging fires (e.g., turbine generator fires) assume fire has not been suppressed.



INCR

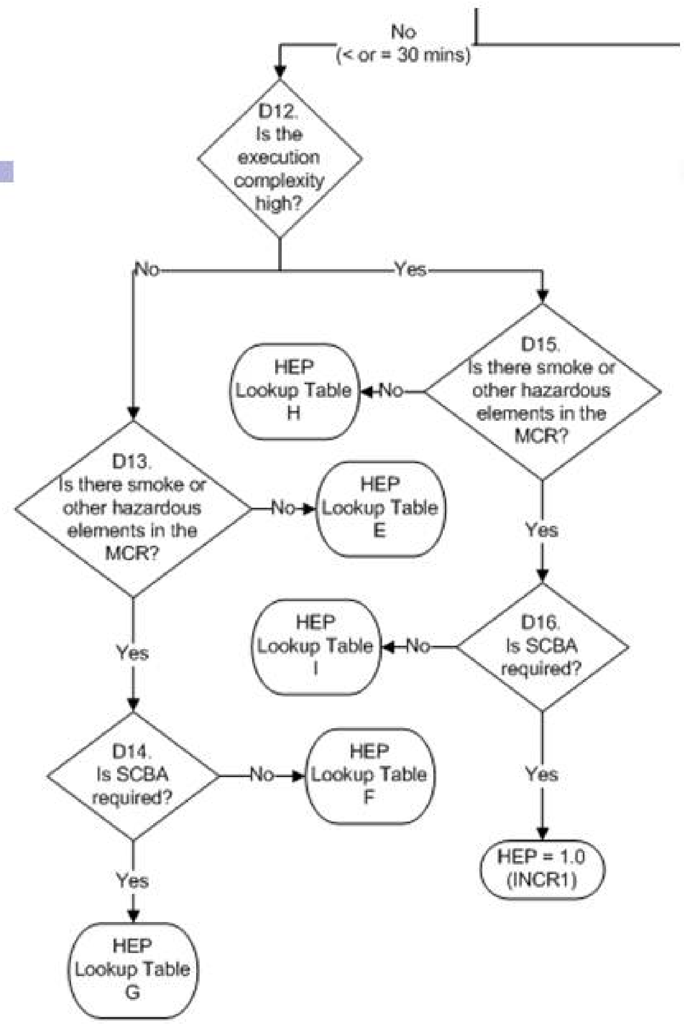
- Scoping HRA for in MCR Actions



A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

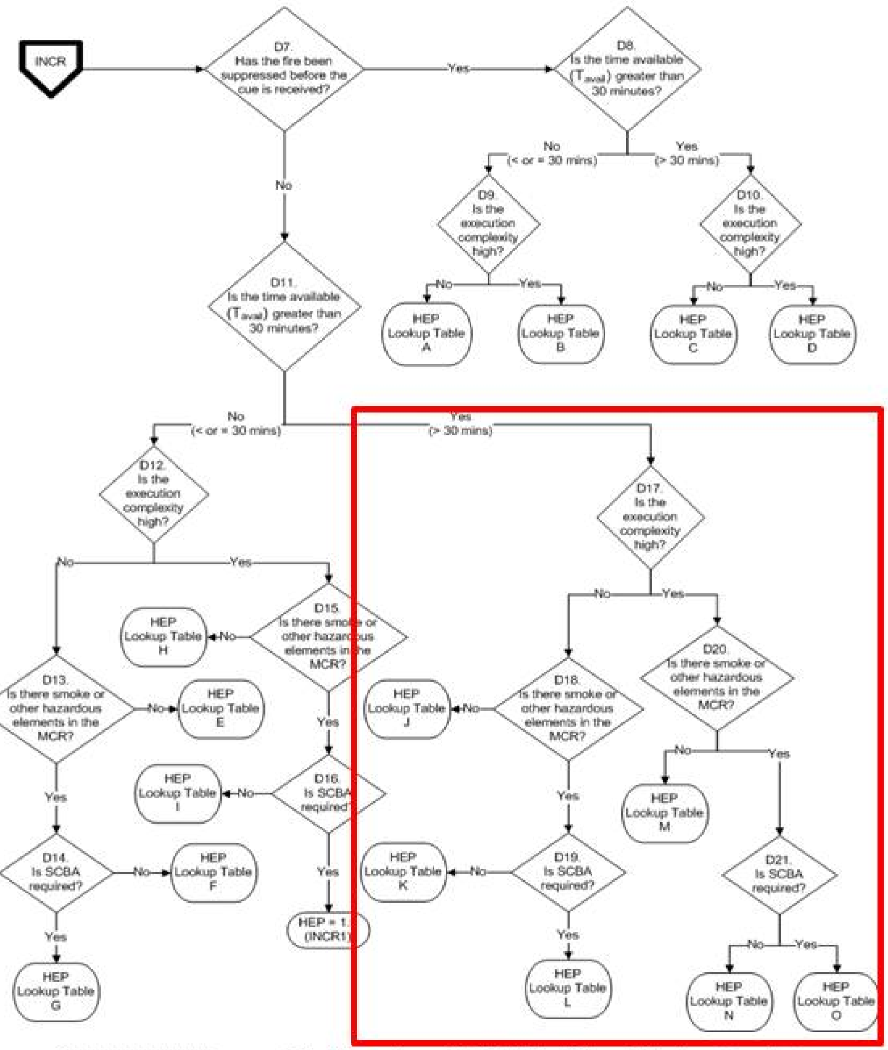
INCR

- Fire on-going
- Short time window (<30 min)



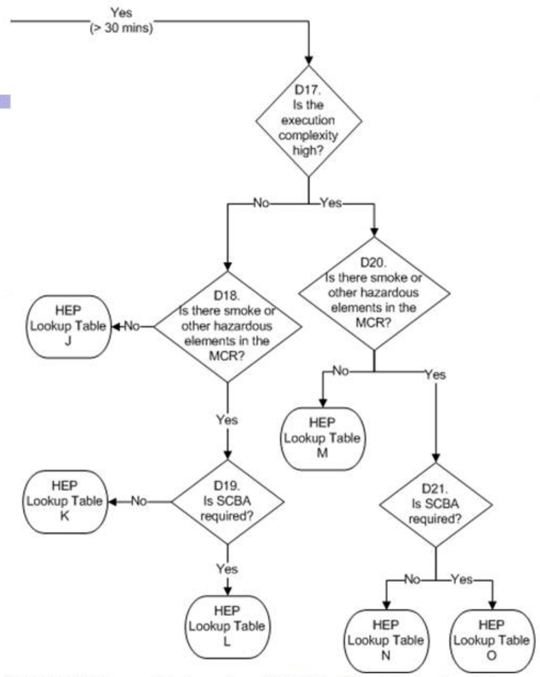
INCR

- Scoping HRA for in MCR Actions



INCR

- Fire on-going
- Long time window (>30 min)

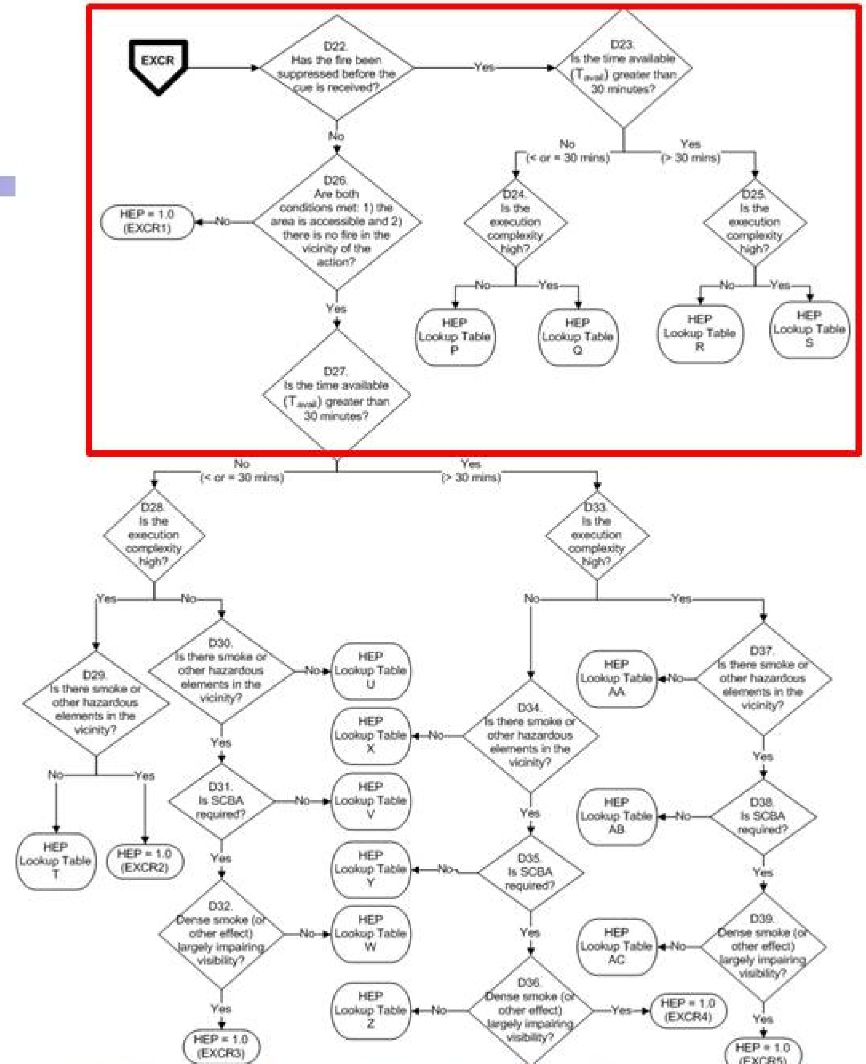


EXCR – Ex-MCR Actions

- Used for the following HFEs:
  - New HFEs identified outside the Internal Events PRA
  - Existing HFEs from the Internal Events that survive quantitative screening
- Addresses diagnosis and execution of the action(s)
  - Diagnosis within the MCR
  - Execution locally (i.e., ex-MCR)
    - If action is require both in the MCR and locally, this tree should be used

EXCR

- Scoping HRA for ex-MCR Actions

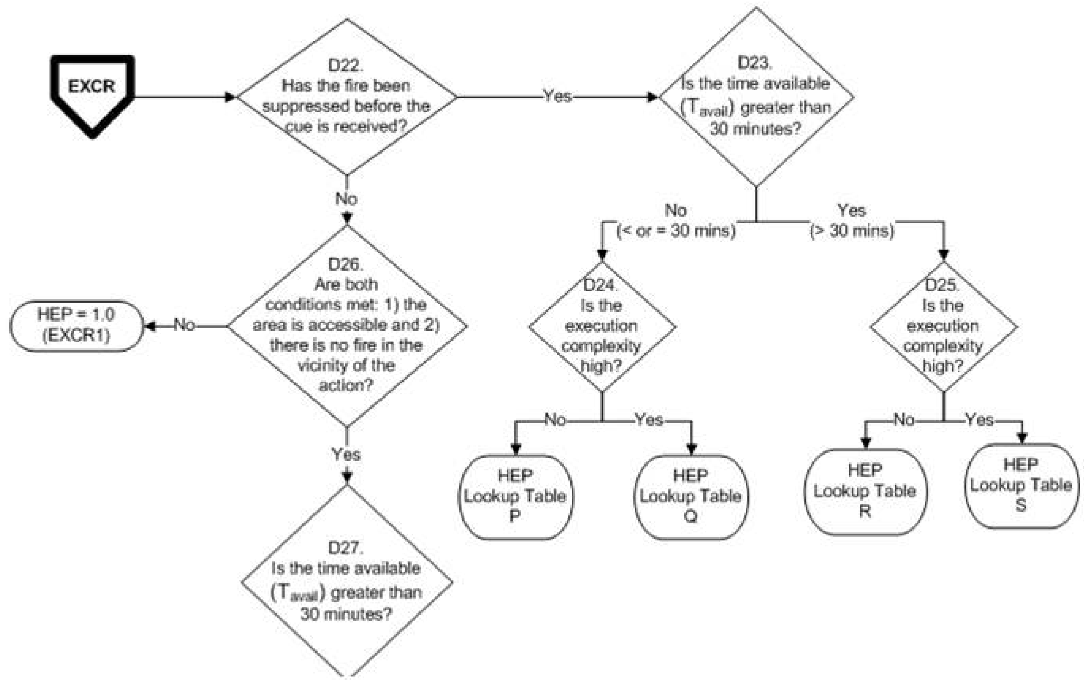


Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Research (RES) & Electric Power Research Institute (EPRI)

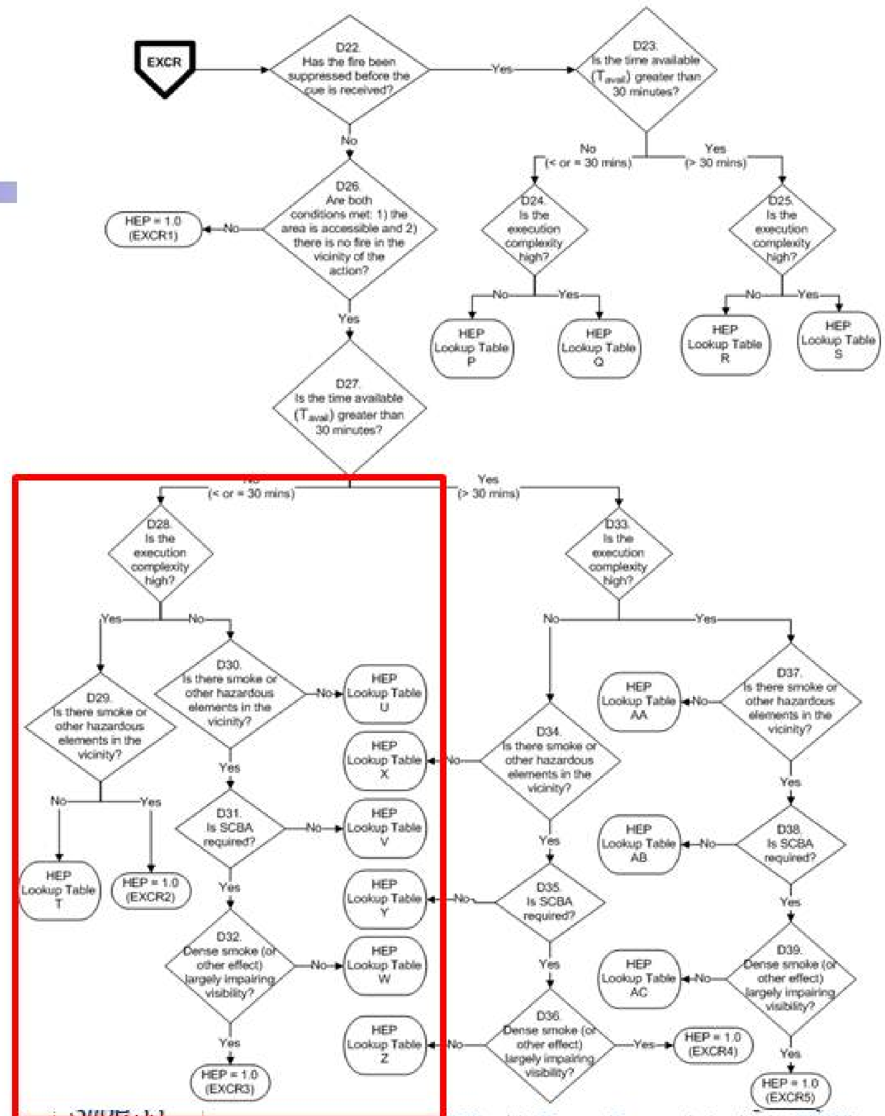
EXCR

- Fire Suppressed?
  - 70 minutes from reactor trip
  - Fire specific timing [FAQ-08-0050]
  - Challenging fires (e.g., turbine generator fires) assume fire has not been suppressed.



EXCR

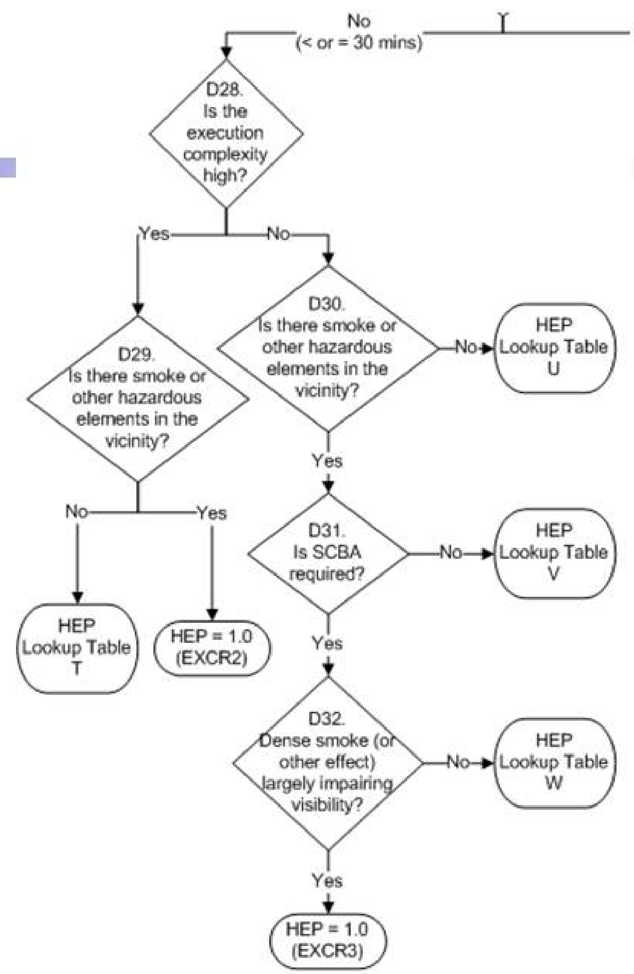
- Scoping HRA for ex-MCR Actions



Research (RES) & Electric Power Research Institute (EPRI)

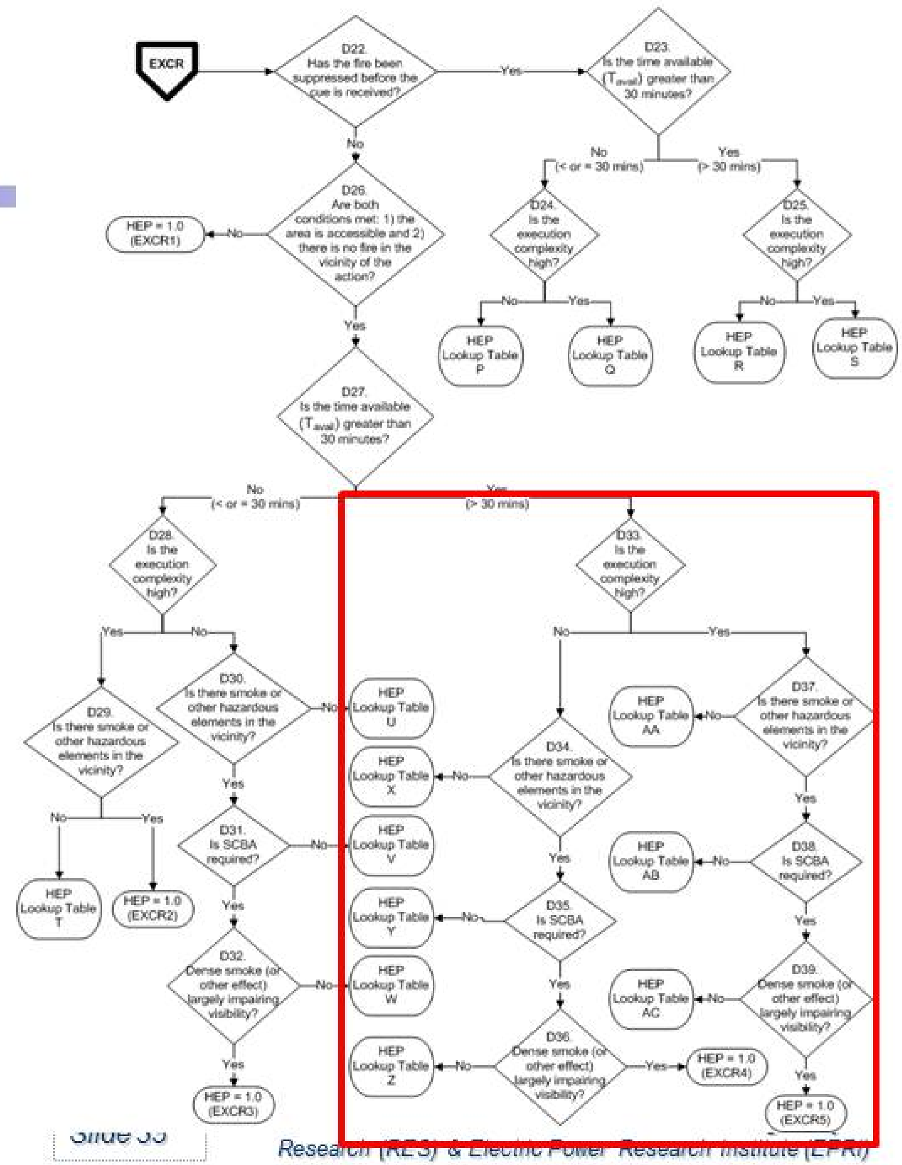
EXCR

- Fire on-going
- Short time window (< 30 min)



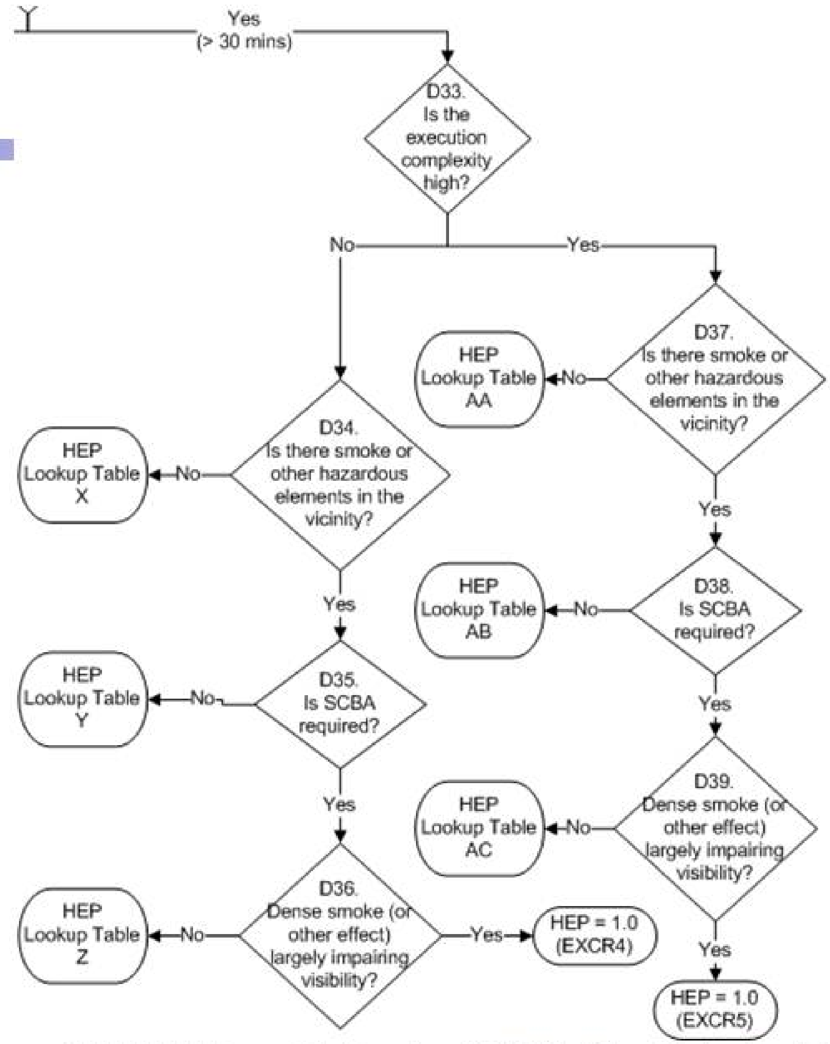
EXCR

- Scoping HRA for ex-MCR Actions



EXCR

- Fire on-going
- Long time window (> 30 min)

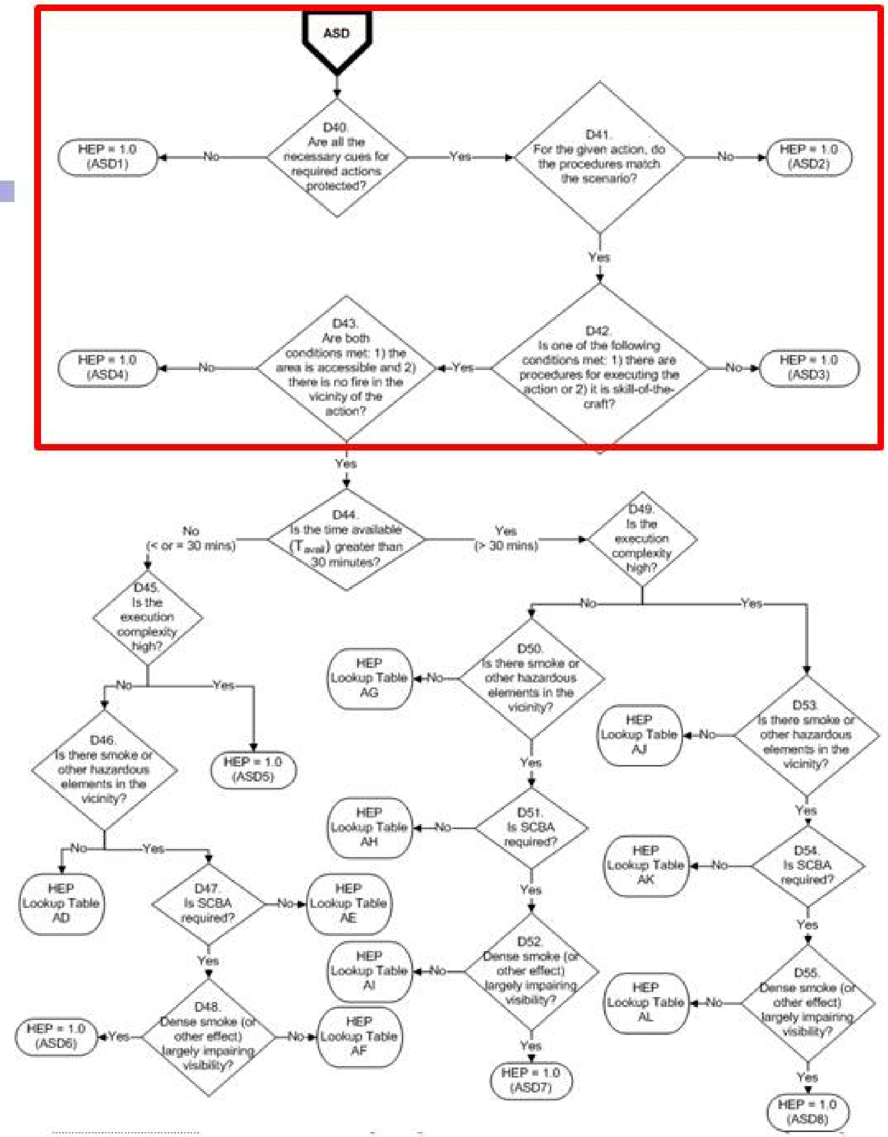


ASD – Alternative Shutdown

- Application to 2 situations:
  - Uninhabitable environment in MCR
  - Transfer of command and control to outside the MCR due to an inability to control the plant (loss of MCR functionality)
    - If the crew decides to stay in the MCR (i.e., direct the crew response and perform actions from the MCR to the extent possible), but collect some information or take some actions outside the MCR as necessary to reach safe shutdown (referred to as *remote shutdown*), actions should be quantified as ex-MCR actions and the EXCR flowchart should be used
- Additional information needed:
  - Identification of the cues necessary for diagnosis and verification that the instruments supporting these cues are protected from the fire effects
  - Determination of whether the action must take place in the direct vicinity of the fire.
  - Estimated level of smoke in the area

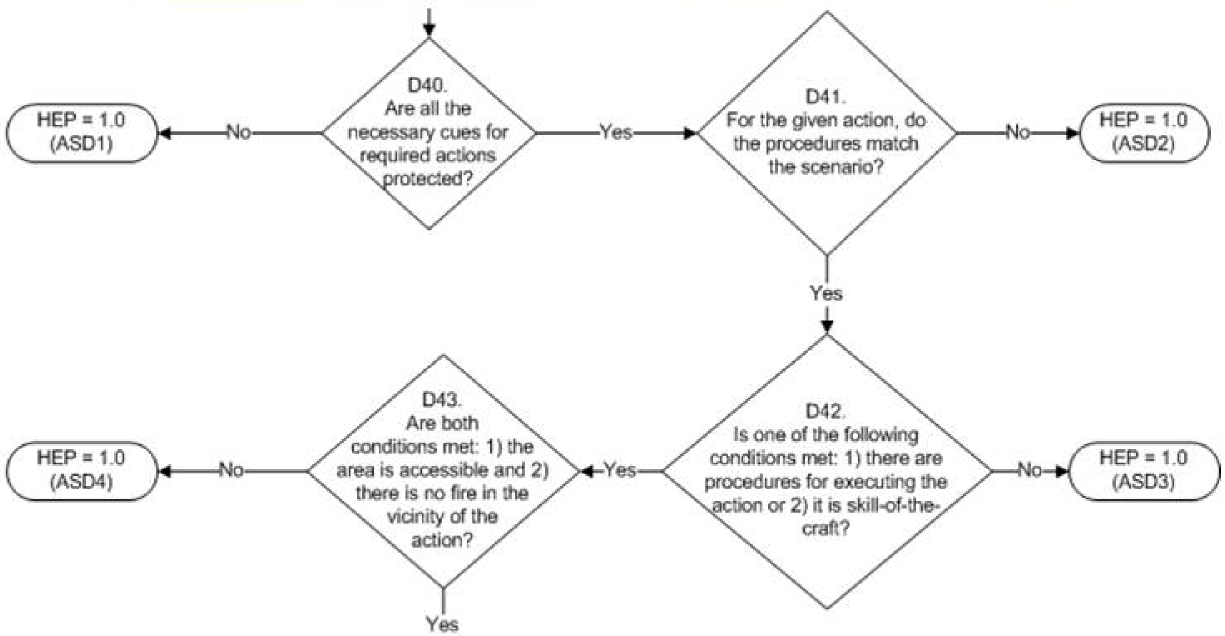
ASD

- Scoping HRA for Alternative Shutdown Actions



Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

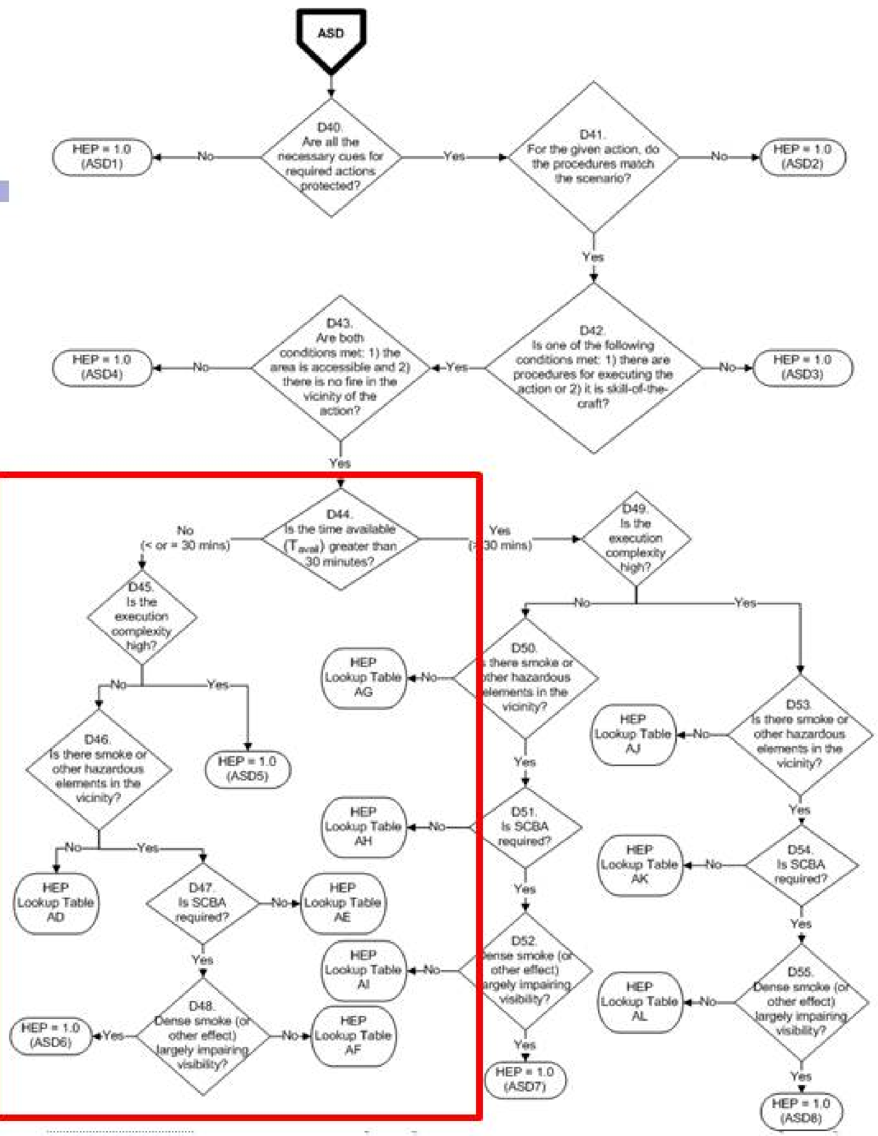
ASD



- D41 refers to diagnosis
- D42 refers to execution

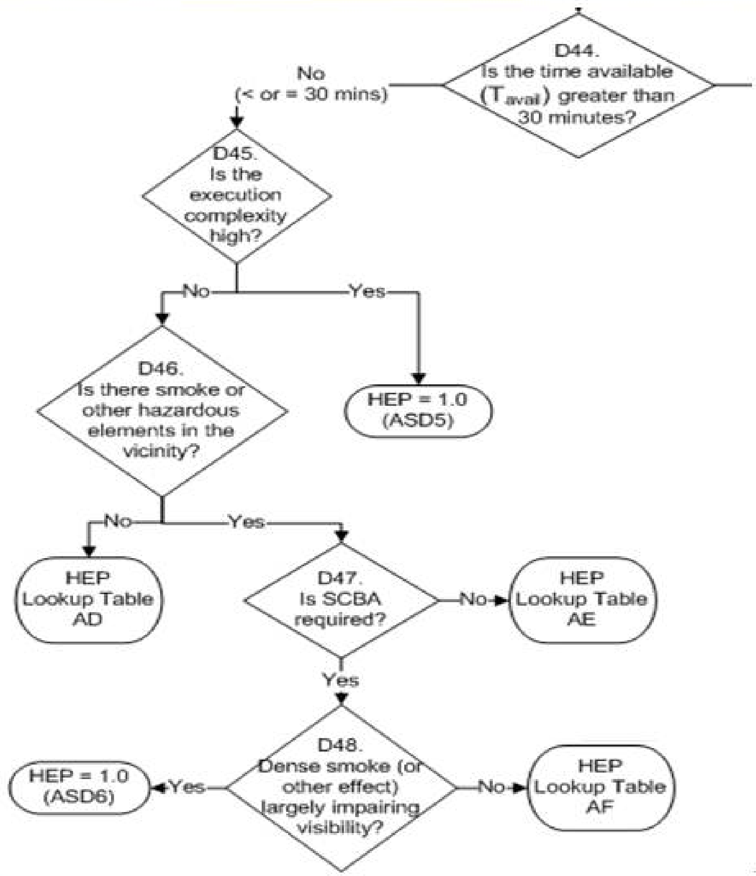
ASD

- Scoping HRA for Alternative Shutdown Actions



Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

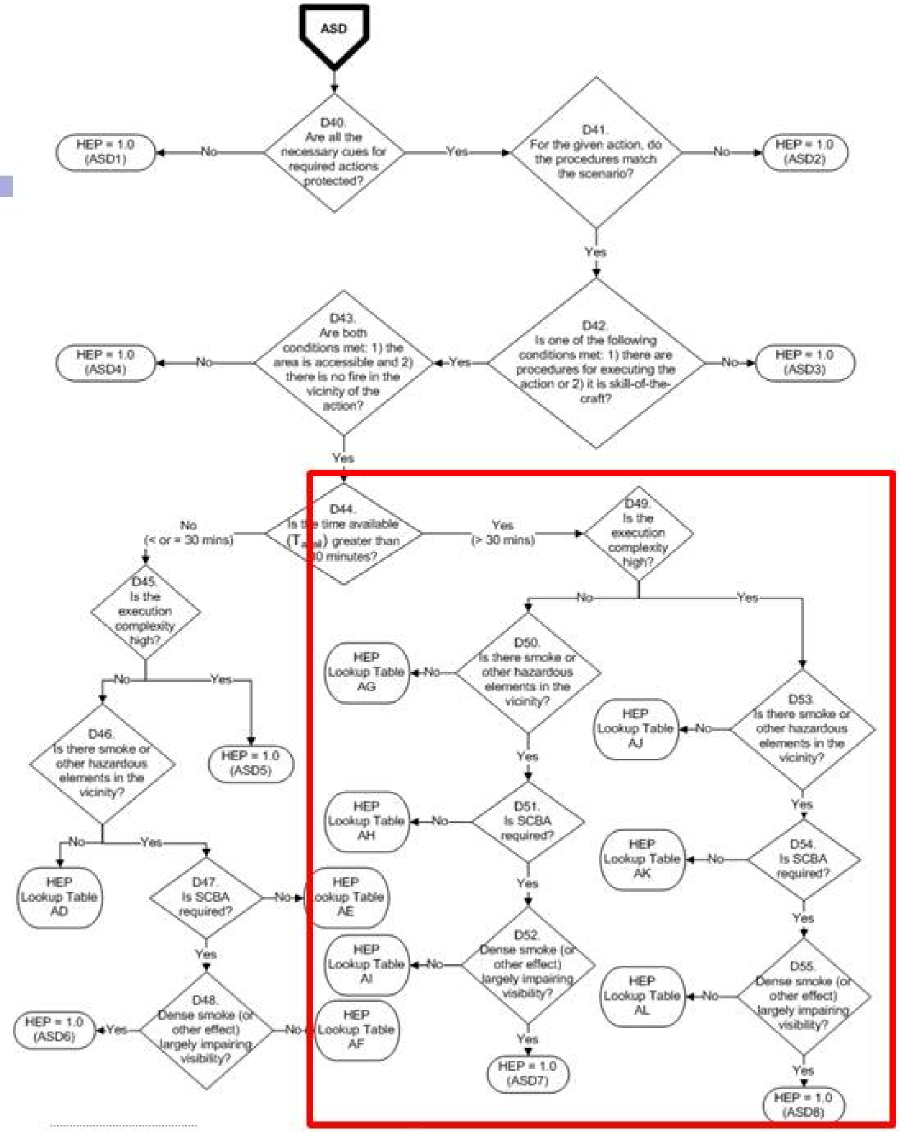
ASD



- Short time window (< 30 min)

ASD

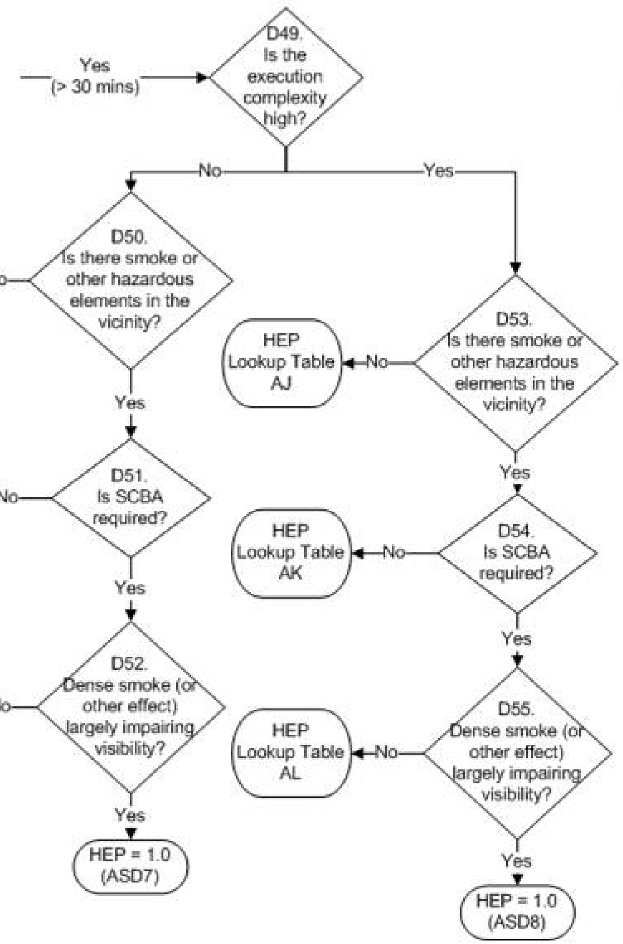
- Scoping HRA for Alternative Shutdown Actions



Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

ASD

- Long time window (> 30 min)



Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 43

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

SPI – EOC or EOO Due to Spurious Instrumentation

- Assumes the EOC or EOO has been committed & quantifies the probability that the error would remain uncorrected
- Assume an EOC or EOO if:
  - The cables are, or cannot definitively be known not to be (exclusion approach), routed through the fire area (Need cable routing information!)
  - The instrumentation is not required for an Appendix R action, such that it cannot be assumed to be protected by a fire barrier wrap
  - A single affected instrument can lead to the action
- Don't assume an EOC or EOO if:
  - Operator is suspicious of the equipment or instrument because it may be "suspect" due to location of fire
  - Demonstrated redundancy and diversity

SPI – Spurious Instrumentation

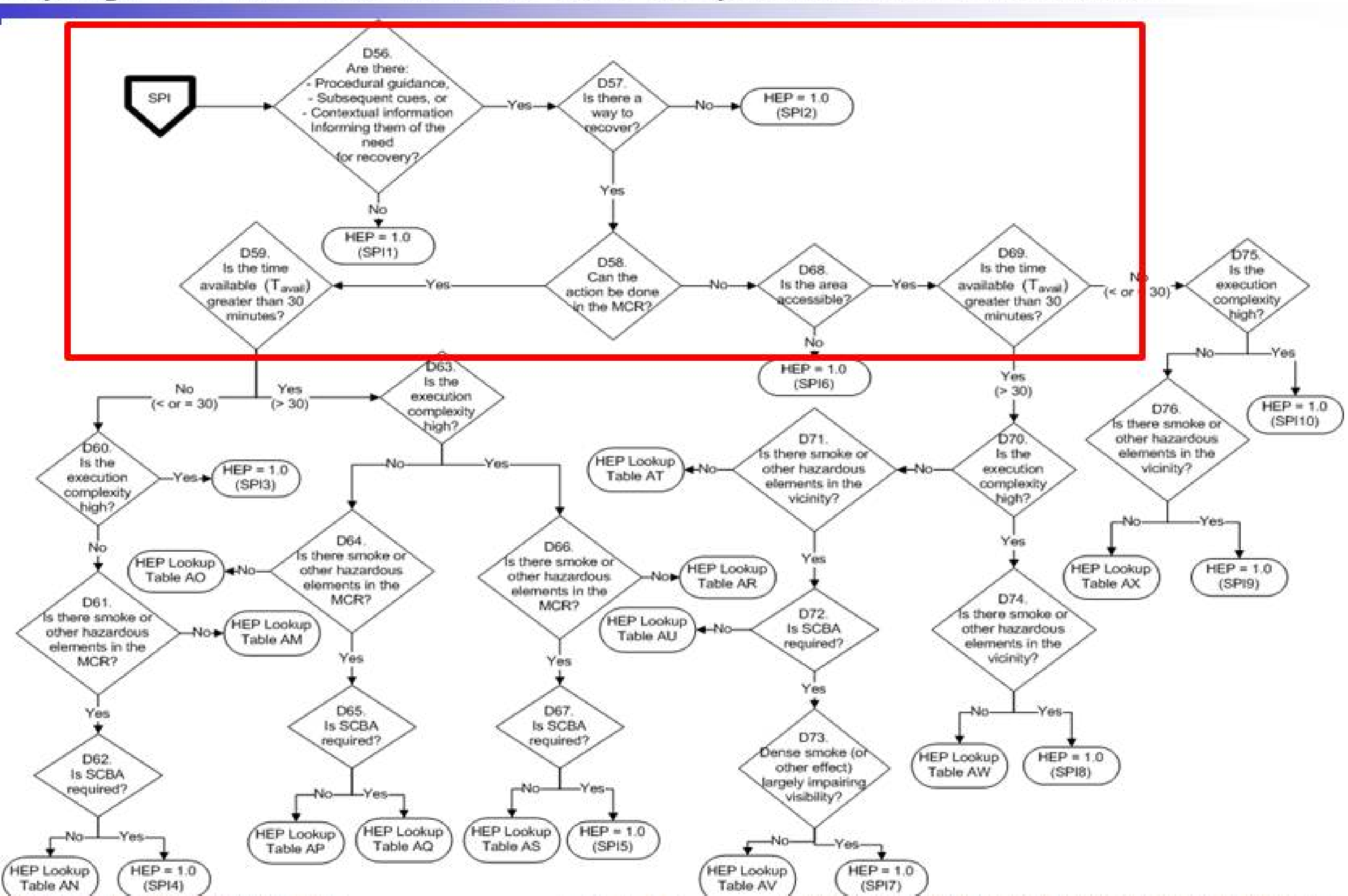
- Spurious instrumentation refers to the instrumentation necessary for the operator to diagnose the action (e.g., expected cues from the procedure)
- Analyst judgment required in cases of partial spurious indication (e.g., 2 out of 4 instruments fail vs. 2 out of 10 instruments fail). In these cases the analyst should consider:
  - How do the instruments fail?
  - Is it likely to cause the operator to fail to diagnose the problem?

SPI – Recovery of an EOC or EOO

- Recovery prompted by either:
  - Procedural guidance
  - Contextual information or subsequent cues in conjunction with existing procedures
- Recognition for need to recover may be either through:
  - Recognition of an error
  - Recognition of the need for the function
- Recovery possible by:
  - Reversal of the action (EOC)
  - Use of alternative system (EOC)
  - Performance of the necessary action (EOO)

SPI

Scoping HRA for EOC or EOO due to spurious instrumentation



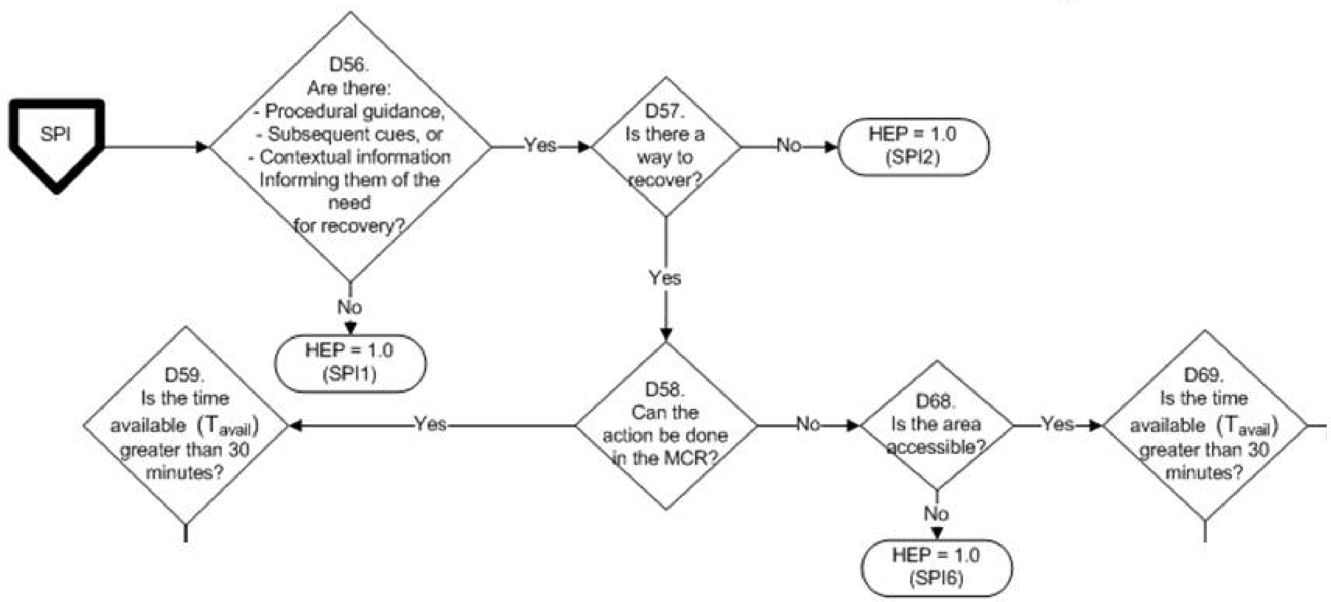
Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 47

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

SPI

Initial questions

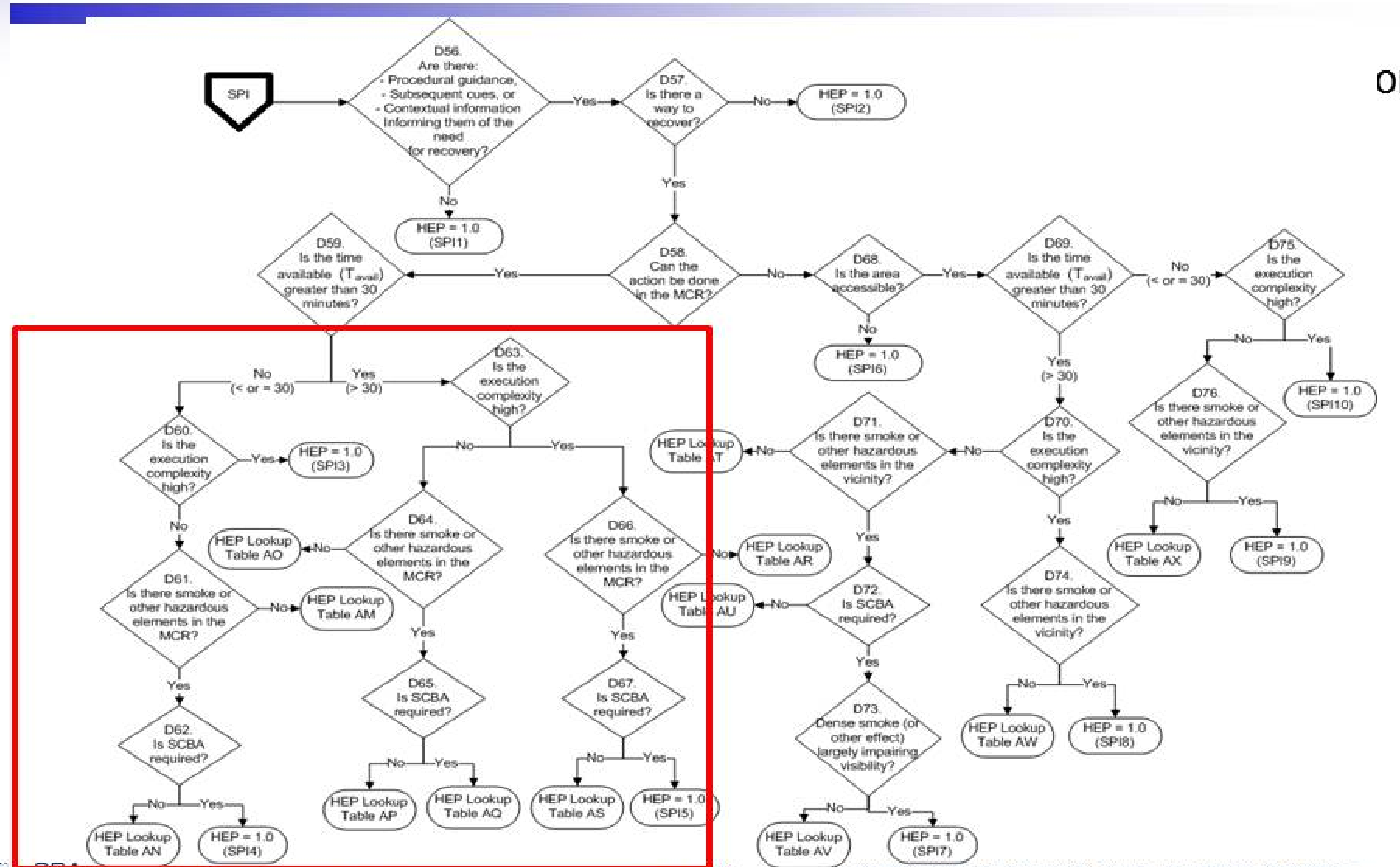


Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 48

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

SPI



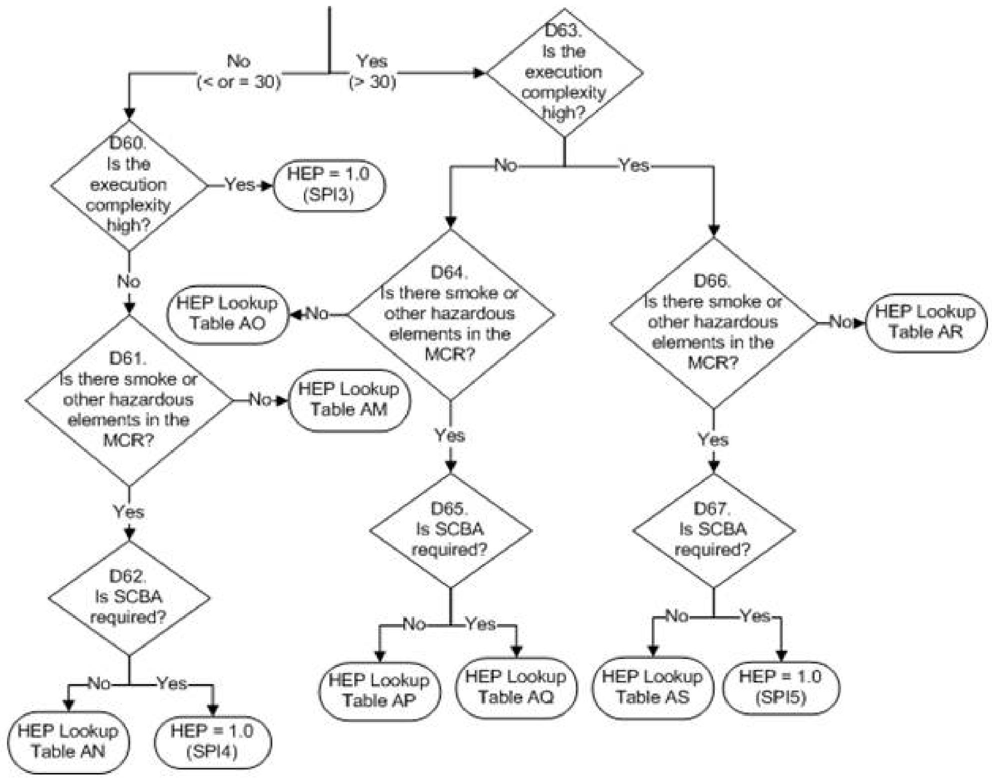
or

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 49

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

SPI



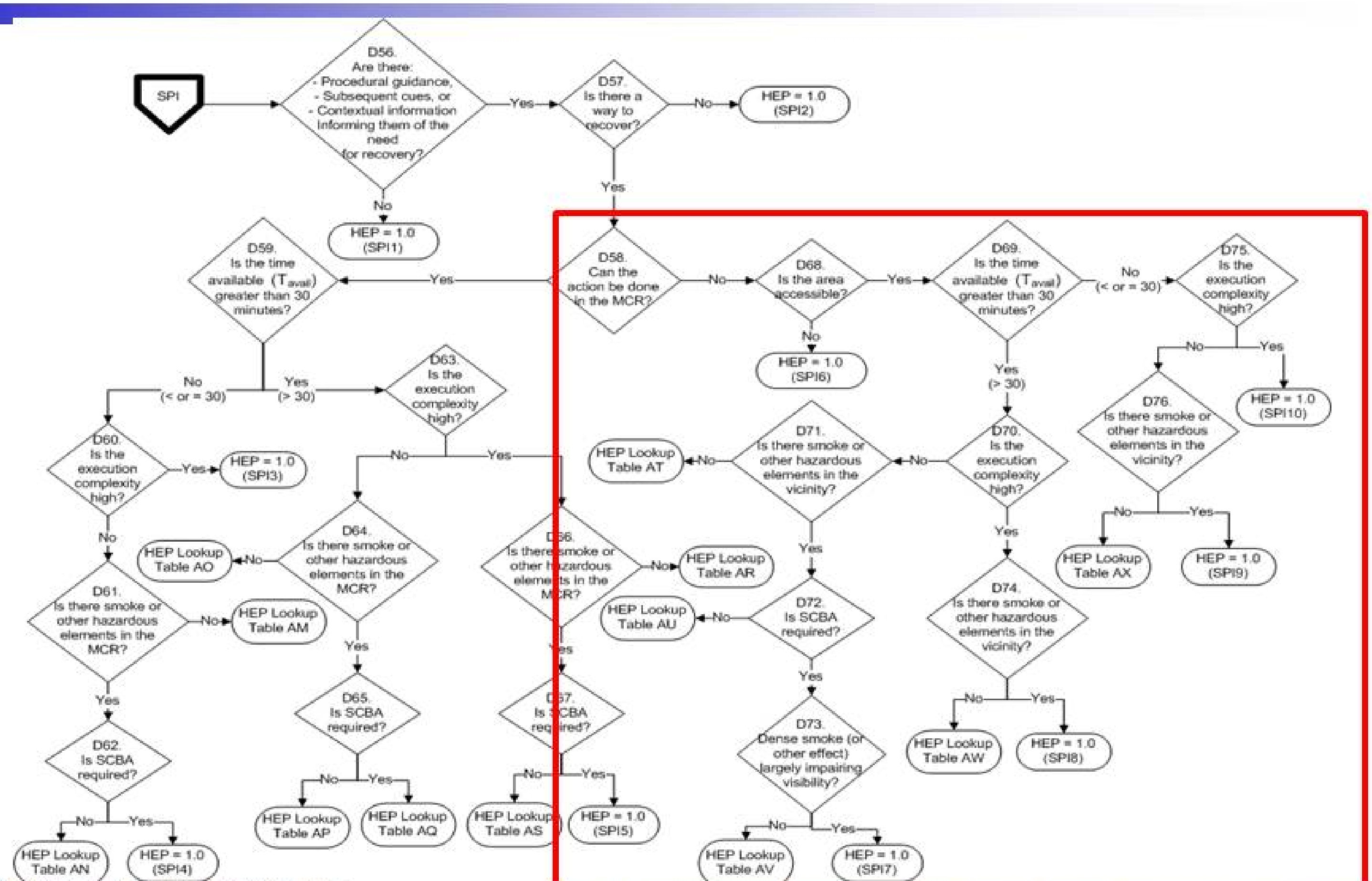
Action completed within the MCR

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 50

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

SPI



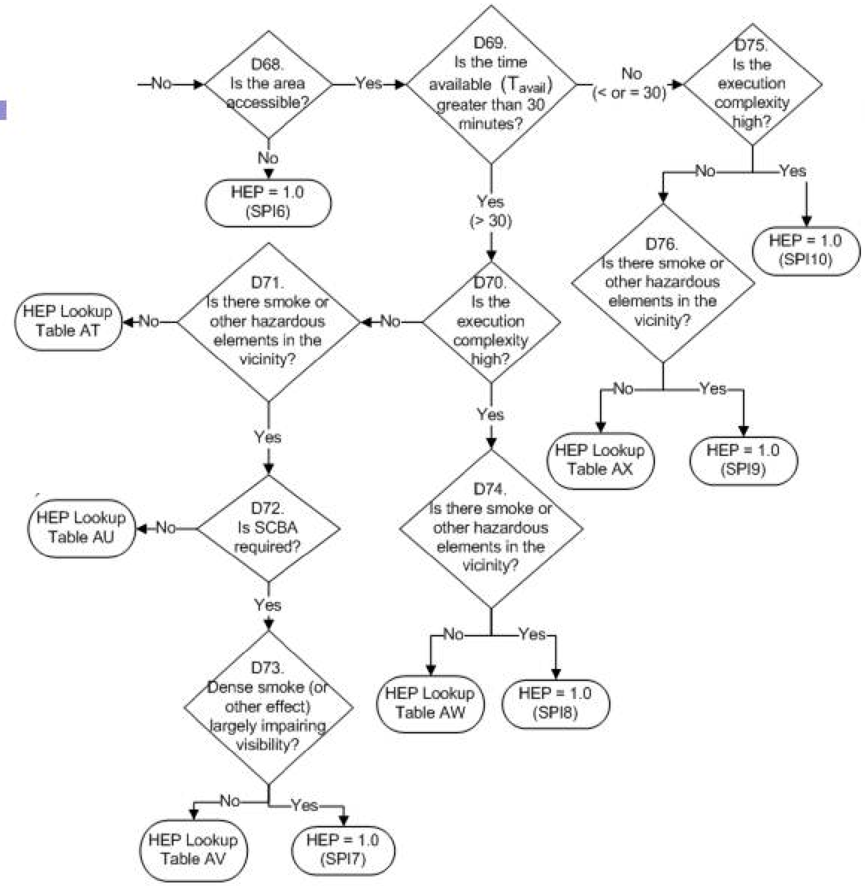
Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 51

Research (RES) & Electric Power Research Institute (EPRI)

SPI

Action completed locally (ex-MCR)



Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 52

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

HEP Values

- Base HEP = 1E-3 (minimally attainable value)
- Within a flowchart, HEP values are based on:
  - Timing of the cue for an action relative to start of fire
  - Length of action time window
  - Level of execution complexity
  - Level of smoke (area of action & travel path)
  - Accessibility of action site (area of action & travel path)

Multipliers Applied to HEPs Within Flowchart

- HEPs adjusted within a flowchart
  - Fire effects ongoing – significant increase
  - Action time window ≤ 30 mins – moderate increase
  - High execution complexity – moderate increase
  - Increases in smoke level – slight increase
  - Decrease in time margin – moderate increase
- HEPs based in part on amount of time margin (TM) available
  - TM < 50%
  - 50% < TM < 100%
  - TM ≥ 100%

Multipliers Applied to HEPs Across Flowcharts

HEP in Base Flowchart	Adjustment Value	HEP in Scoping Flowchart
INCR	2	EXCR
EXCR	2	ASD
INCR for in-MCR actions; EXCR for ex-MCR actions	5	SPI

Change in PSF	Scoping Approach Multipliers
Fire effects ongoing (i.e., < 70 minutes from the start of the fire)	10
Action time window ≤ 30 minutes	5
High execution complexity	5
Increases in smoke level	2
Decreases in time margin: from ≥ 100% to 50%-99% from ≥ 50% to < 50%	 5 Set HEP = 1.0

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 55

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Summary of Scoping Quantification

- Purpose:
  - Offers less conservative and more realistic HEPs compared to the screening approach
  - More conservative but less resource intensive than more detailed HRA methods
- Categories:
  - In-MCR or local (ex-MCR) actions
  - Alternative shutdown
  - Recovery of errors due to spurious instrumentation
- Quantification:
  - Relies on assessment of feasibility of actions, time margin, and simple judgments about a few PSFs
  - Quantification is through the use of flowcharts

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA - Scoping Method

Slide 56

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
    a) Screening
    b) Scoping
    c) EPRI approach (detailed)
    d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

3.7. Scoping Examples

SCOPING EXAMPLE

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 2

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

General assumptions for examples

- Actions have applicable plant emergency procedures and fire procedures
- Fire does not impact control room environment
- There is a full area burn out
- At least one train of heat removal is available as demonstrated by Appendix R
- Adequate inventory in fire protection system (FPS)
- Note: Similar examples are being used to illustrate screening, scoping and detailed approaches, but scenario specifics may not be identical

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 3

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 1A: Operator fails to align FPS water to AFW pumps

- The auxiliary feedwater pumps take water from the auxiliary feedwater storage tank.
- With low low level in the tank, the operator would align the FPS (fire protection system) to the pumps.
- Consider the tank low low level (10%) would be reached in 10 hours. At this level the operator will receive an alarm (sound and light)
- The operator has to open manual valves. (at least one valve)
- At 10% low low level the local operator must align the FPS.
- Operator has 1 hour before loss of cooling from low low level cue

Example 1A: Operator fails to align FPS water to AFW pumps

- Local action
- Long term action (10 hours)
- Time available is large (60 minutes)
- Time for carrying out action:
  - Diagnosis (cognition) time = 2 minutes
  - Execution time = 10 minutes

Example 1A: Minimum Criteria

1. ✓ Procedures
   - Plant procedures covering each operator action being modeled
   - Support both diagnosis & execution of the action

2. ✓ Training – on the procedures and the actions

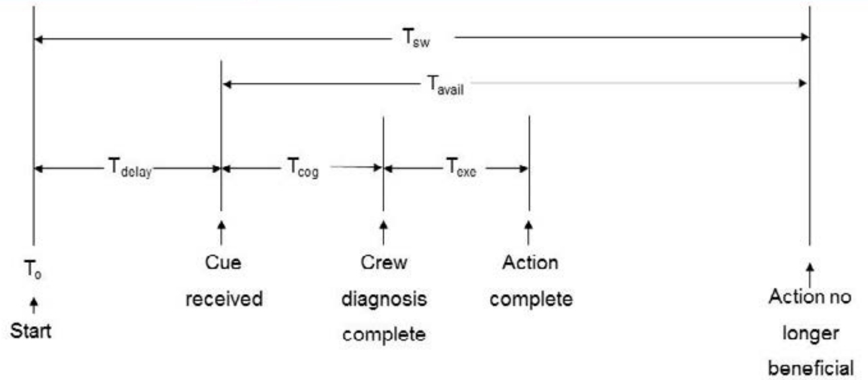
3. ✓ Availability and accessibility of equipment

Example 1A: Feasibility

- Timing analysis:
  - Time available (60 mins) > Time required (12 mins)
- Cues available to aid diagnosis
  - Cable tracing was done on AFWST alarms
- Fire activity would not prevent the execution of the actions
- Enough crew members available to complete the action

Example 1A: Time Margin

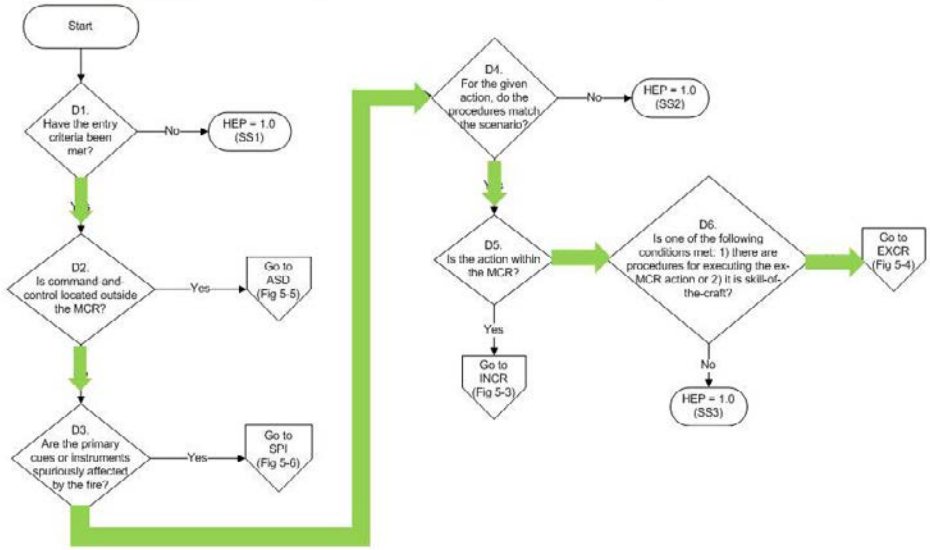
$$\text{Time Margin} = \frac{T_{avail} - (T_{cog} + T_{exe})}{(T_{cog} + T_{exe})} * 100\% = \frac{60 - (2+10)}{(2+10)} * 100\% = 400\%$$



Example 1A: Assessing Key Conditions & PSFs

Condition	Status
Do the procedures match the scenario?	Yes
Is the execution complexity high?	No
Is the fire suppressed when the cue is received?	Yes
What's the time window (T_{avail})?	60 min
Is there any smoke or other hazardous elements in the action areas?	No
Is the action area accessible?	Yes

Example 1A: Search Scheme

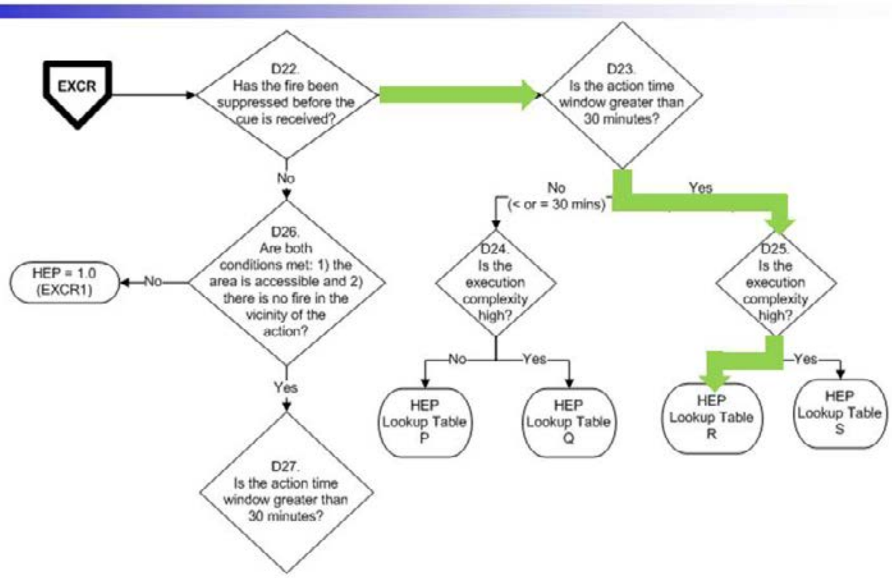


Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 10

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 1A: EXCR



Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 11

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 1A: EXCR Lookup Table

HEP Lookup Table	Time Margin	HEP	HEP Label
R	> 100%	0.002	EXCR12
	50 – 99%	0.01	EXCR13
	< 50%	1.0	EXCR14

Example 1B: Operator fails to align FPS water to AFW pumps with failed alarm

- Same basic scenario as Example 1A
  - The auxiliary feedwater pumps take water from the auxiliary feedwater storage tank.
  - When low low level in the tank is reached, the operator needs to align the FPS (fire protection system) to the pumps.
- Cable tracing has not been done, therefore assume fire fails the AFWST alarm at the 10% level
  - Assumed that the action would not occur (error of omission) and the spurious indication flowchart must be used!
- Fire procedures direct operator to check tank level locally and consider refilling if needed
  - Diagnosis time is increased

Example 1B:
Operator fails to align FPS water to AFW pumps with failed alarm

- Local action
- Long term action (10 hours)
- Time available is large (60 minutes)
- Time for carrying out action:
  - Diagnosis (cognition) time = 15 minutes
  - Execution time = 10 minutes

Example 1B:
Minimum Criteria

1. ✓ Procedures
   - Fire procedures covering each operator action being modeled
   - Support both diagnosis & execution of the action

2. ✓ Training – on the procedures and the actions

3. ✓ Availability and accessibility of equipment

Example 1B: Feasibility

- Timing Analysis:
  - Time available (60 mins) > Time required (25 mins)
- Cues available to aid recovery
- Fire activity would not prevent the execution of the actions
- Enough crew members available to complete the action

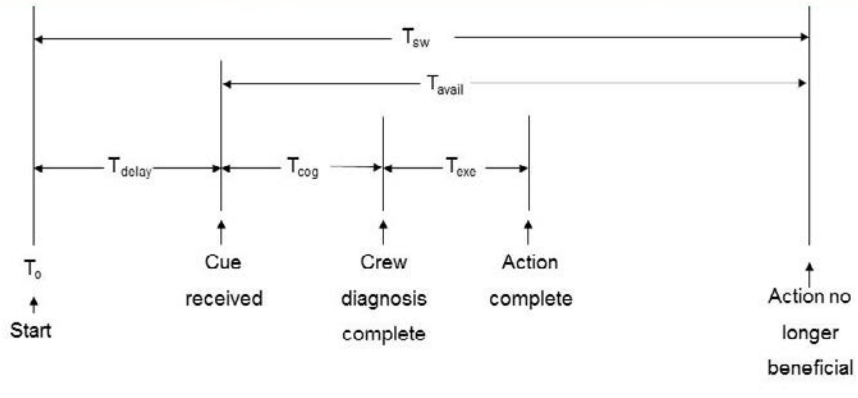
Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 16

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 1B: Time Margin

$$\text{Time Margin} = \frac{T_{avail} - (T_{cog} + T_{exe})}{(T_{cog} + T_{exe})} * 100\% = \frac{60 - (15 + 10)}{(15 + 10)} * 100\% = 140\%$$



Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 17

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 1B: Assessing Key Conditions & PSFs

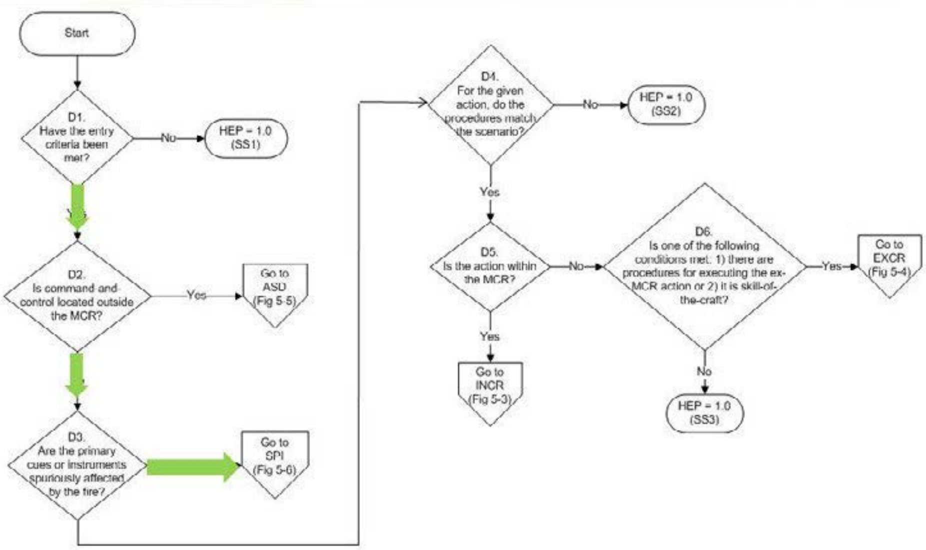
Condition	Status
Do the procedures match the scenario?	Yes
Is the execution complexity high?	No
Is the fire suppressed when the cue is received?	Yes
What's the time window (T_{avail})?	60 min
Is there any smoke or other hazardous elements in the action areas?	No
Is the action area accessible?	Yes

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 18

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 1B: Search Scheme

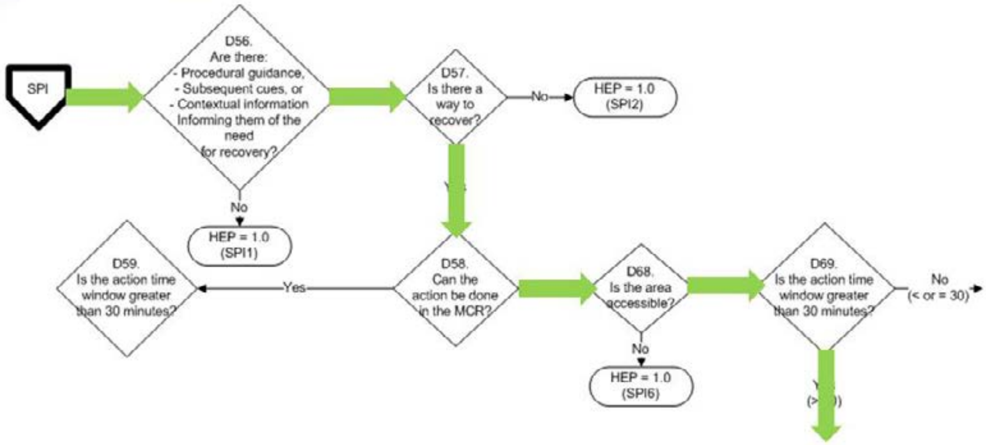


Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 19

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 1B: SPI

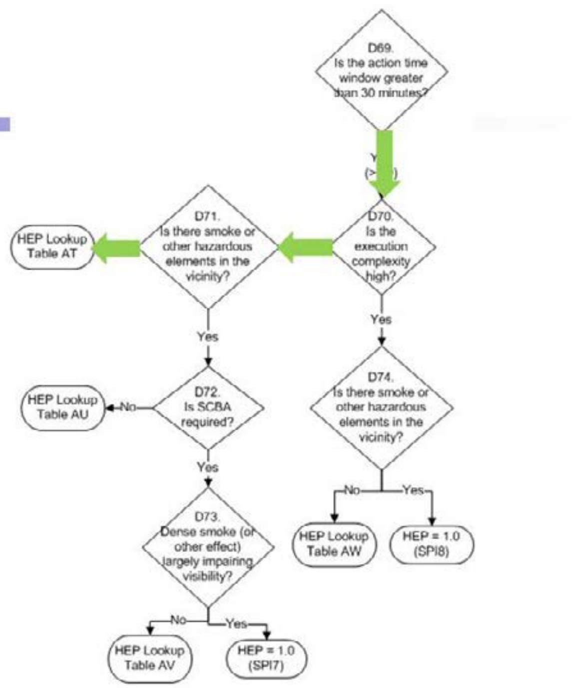


Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 20

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 1B: SPI



Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 21

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 1B:
SPI Lookup Table

HEP Lookup Table	Time Margin	HEP	HEP Label
AT	> 100%	0.1	SPI27
	50 – 99%	0.5	SPI28
	< 50%	1.0	SPI29

Example 2A:
Operator fails to initiate bleed & feed

- The action to initiate bleed and feed will be done when the SGs are almost in dry out
- Cue to initiate bleed and feed is when 2 SGs are at less than 15% WR level
- In this case all indications of level are accurate
- With the main feedwater and auxiliary feedwater systems unavailable at the beginning of the initiating event, the SG goes to dry out in 45 minutes

Example 2A:
Operator fails to initiate bleed & feed

- MCR action
- Total system time window = 45 minutes for the SGs to dry out
- Time available = 25 minutes
- Time for carrying out action:
  - Diagnosis (cognition) time = 3 minutes
  - Execution time = 8 minutes

Example 2A:
Minimum Criteria

1 ✓ Procedures
- Plant procedures covering each operator action being modeled
- Support both diagnosis & execution of the action

2 ✓ Training – on the procedures and the actions

3 ✓ Availability and Accessibility of Equipment

Example 2A: Feasibility

- Timing Analysis:
  - Time available (25 mins) > Time required (11 mins)
- Cues available to aid diagnosis
  - All indications of SG level are accurate
- Fire activity would not prevent the execution of the actions
- Enough crew members available to complete the action

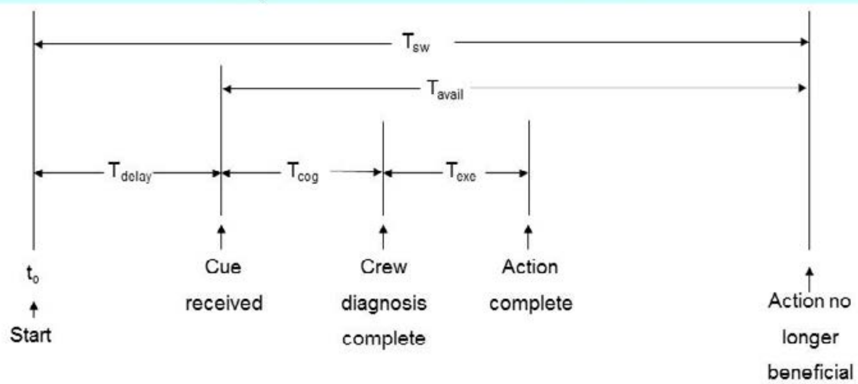
Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 26

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2A: Time Margin

$$\text{Time Margin} = \frac{T_{avail} - (T_{cog} + T_{exe})}{(T_{cog} + T_{exe})} * 100\% = \frac{25 - (3+8)}{(3+8)} * 100\% = 127\%$$



Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 27

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2A:
Assessing Key Conditions & PSFs

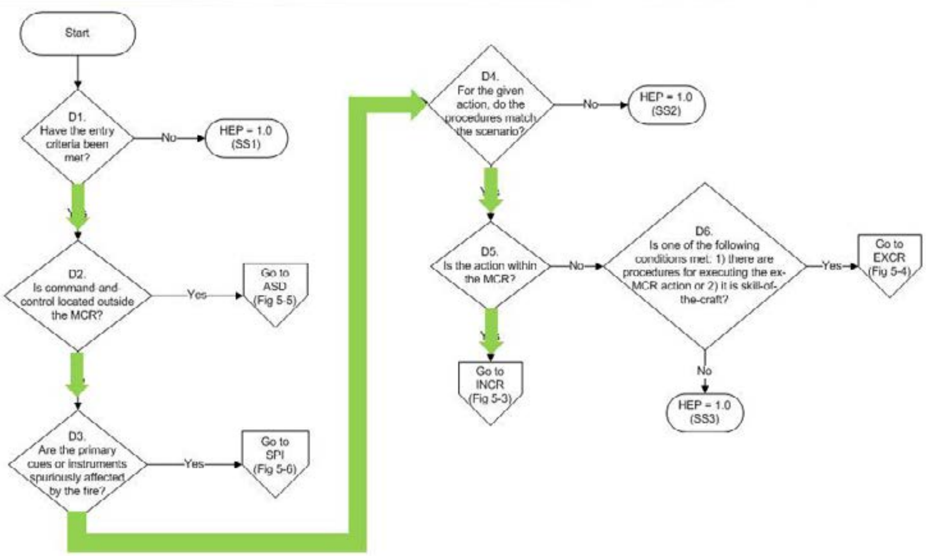
Condition	Status
Do the procedures match the scenario?	Yes
Is the execution complexity high?	No
Is the fire suppressed when the cue is received?	No
What's the time window (T_{avail})?	25 min
Is there any smoke or other hazardous elements in the action areas?	No
Is the action area accessible?	Yes

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 28

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2A:
Search Scheme

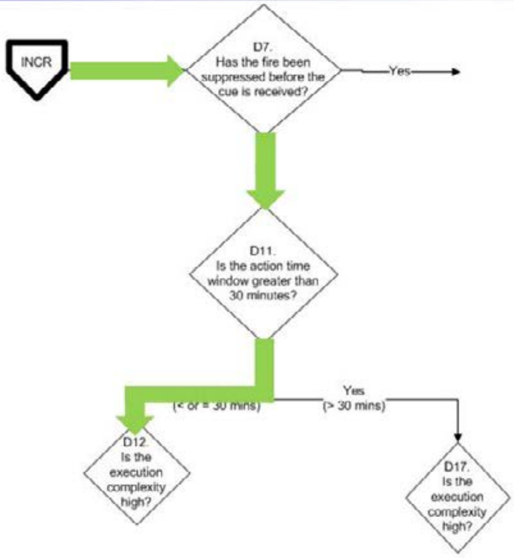


Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 29

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2A: INCR (part 1)

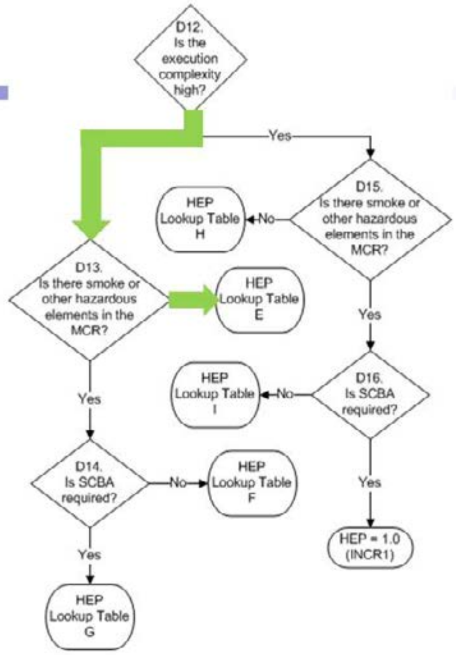


Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 30

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2A: INCR (part 2)



Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 31

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2A: INCR Lookup Table

HEP Lookup Table	Time Margin	HEP	HEP Label
E	> 100%	0.05	INCR14
	50 – 99%	0.25	INCR15
	< 50%	1.0	INCR16

Example 2B: Operator fails to initiate bleed & feed and use of fire procedures

- The action to initiate bleed and feed will be done when the SGs are almost in dry out
- Cue to initiate bleed and feed is when 2 SGs are at less than 15% WR level
- In this case half of the indicators of SG level are failed and fire procedures must be used to identify which indicators are accurate
- With the main feedwater and auxiliary feedwater systems unavailable at the beginning of the initiating event, the SG goes to dry out in 45 minutes

Example 2B: Operator fails to initiate bleed & feed and use of fire procedures

- MCR action
- Total system time window = 45 minutes for the SGs to dry out
- Time available = 25 minutes
- Time for carrying out action:
  - Diagnosis (cognition) time = 8 minutes
  - Execution time = 8 minutes

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 34

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2B: Minimum Criteria

1. ✓ Procedures
   - Fire procedures covering each operator action being modeled
   - Support both diagnosis & execution of the action
2. ✓ Training – on the procedures and the actions
3. ✓ Availability and accessibility of equipment

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 35

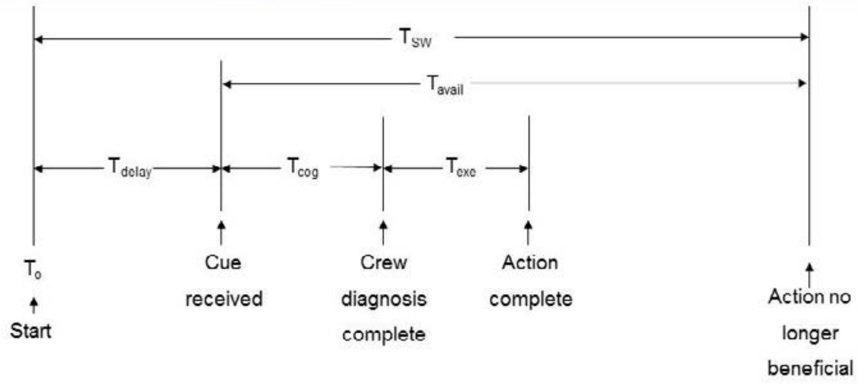
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2B: Feasibility

- Timing Analysis:
  - Time available (25 mins) > Time required (16 mins)
- Cues available to aid diagnosis
  - Some indications of SG level are accurate
  - Fire procedures used to determine which indicators to trust
- Fire activity would not prevent the execution of the actions
- Enough crew members available to complete the action

Example 2B: Time Margin

$$\text{Time Margin} = \frac{T_{avail} - (T_{cog} + T_{exe})}{(T_{cog} + T_{exe})} * 100\% = \frac{25 - (8+8)}{(8+8)} * 100\% = 56\%$$



Example 2B: Assessing Key Conditions & PSFs

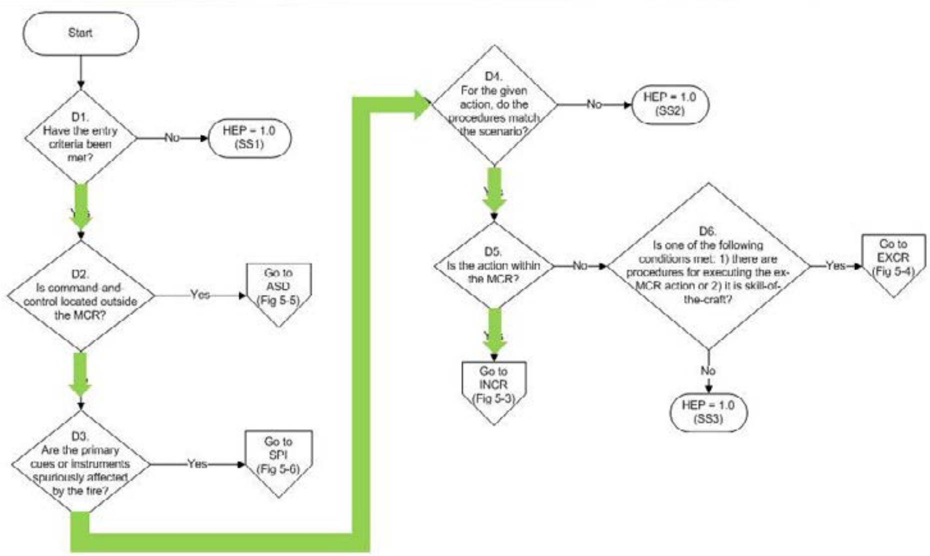
Condition	Status
Do the procedures match the scenario?	Yes
Is the execution complexity high?	No
Is the fire suppressed when the cue is received?	No
What's the time window (T_{avail})?	25 min
Is there any smoke or other hazardous elements in the action areas?	No
Is the action area accessible?	Yes

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

Slide 38

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2B: Search Scheme

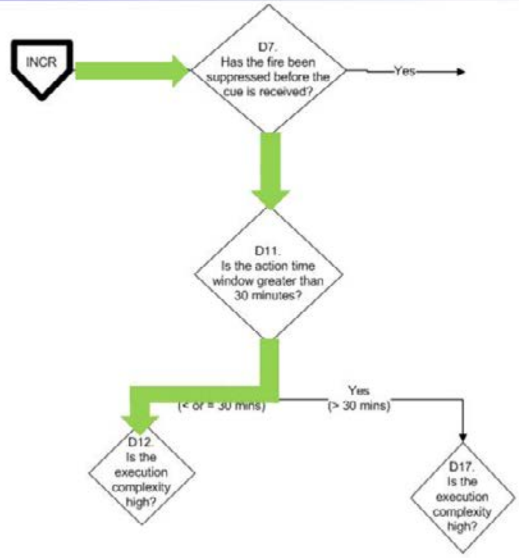


Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – Scoping Analysis Examples

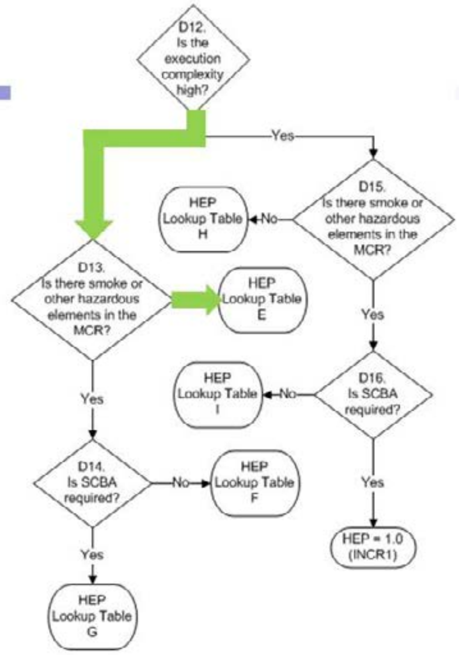
Slide 39

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Example 2B: INCR (part 1)



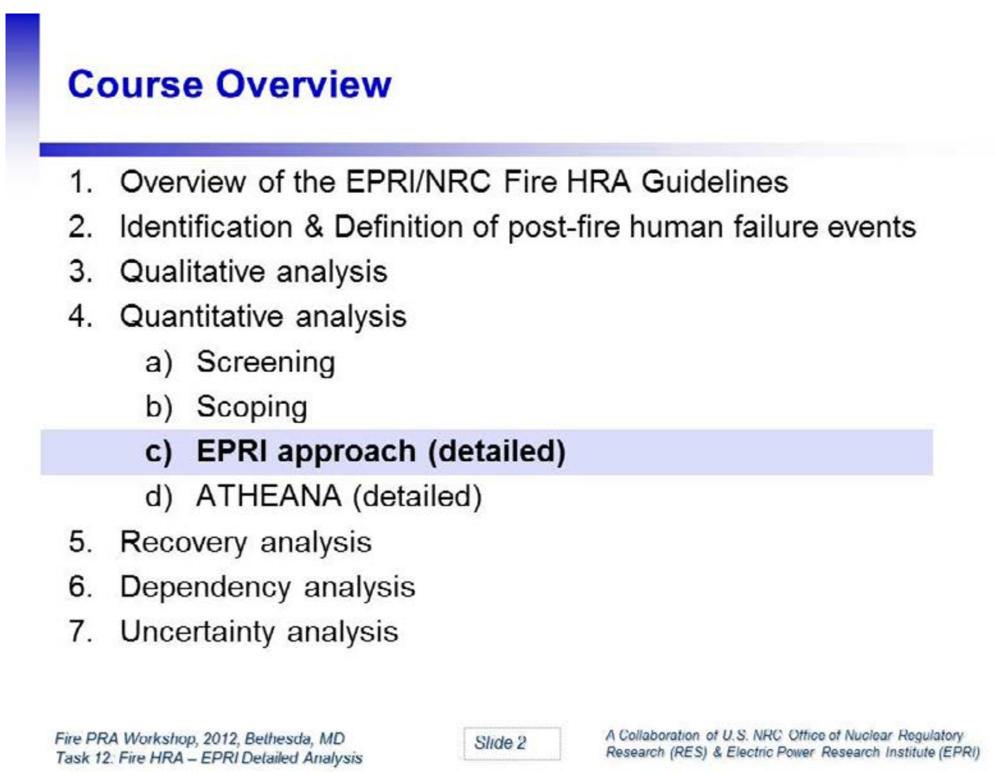
Example 2B: INCR (part 2)



Example 2B: INCR Lookup Table

HEP Lookup Table	Time Margin	HEP	HEP Label
E	≥ 100%	0.05	INCR14
	50 – 99%	0.25	INCR15
	< 50%	1.0	INCR16

3.8. EPRI Approach to Detailed Fire HEP Quantification



Fire HRA Module Training Objectives

1: Be able to name the **steps in the process** for conducting a Fire HRA.

2: Be able to list the **different categories** of Fire HRA human failure events.

3: Demonstrate knowledge of ASME/ANS PRA Standard **high level requirements (HLRs).**

4: Be able to identify **context and performance shaping factors** used in the analysis of post-fire human failure events.

5: Be able to list the quantification methods available for HEPs.

6: Understand the concept and importance of addressing **dependencies** between post-fire HRA events.

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 3

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Outline of the EPRI Approach to Detailed Fire HRA Module

- Introduction/Relation to NUREG/CR-6850 (EPRI 1011989) Tasks
- Applicable PRA Standard High Level Requirements
- Overview of Quantitative Methods in the EPRI Approach:
  - Cause-Based Decision Tree Overview (Cognitive)
  - HCR/ORE Overview (Cognitive for Time-Critical)
  - THERP (Execution)
- Definition & subsequent Qualitative Analysis
  - Fire Context
  - Performance Shaping Factor
- Method Selection & Quantification
- Summary

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 4

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

What is *Detailed Fire HRA*?

Consists of HRA tasks that develop human error probabilities (HEPs) for the modeled human failure events (HFEs)

- HEP used in FPRA quantification
- HEP development provides qualitative insights on results drivers

Typically done to PRA Standard Capability Category II

- Risk-significant scenarios

Uses most of the steps in the **HRA Process**:

1. Identification & Definition of HFE
2. Qualitative analysis – context & performance shaping factors
3. Quantitative analysis – method selection & quantification of HEP
    a) Screening
    b) Scoping
    c) Detailed HRA: EPRI approach or ATHEANA
4. Provides input to subsequent Fire HRA tasks
    - Dependency analysis
    - Uncertainty analysis

General Approaches to Quantification

1. Screening: Slightly modified from NUREG/CR-6850 (EPRI 1011989) to reduce the HEPs for late HFEs (after fire is out) – covered previously
2. Scoping FHRA quantification approach – covered previously
    - Less conservative than screening, but designed to be slightly more conservative than detailed approaches
    - Some actions may not be able to meet some of the criteria (result in an HEP of 1.0)
3. Two detailed fire HRA quantification approaches, modified for application in fire scenarios
    - EPRI – covered in this module
        - Cause-Based Decision Tree (CBDT) & HCR/ORE; THERP
    - ATHEANA – covered after this module

Fire HRA Process Steps

NUREG/CR-6850 Task	Fire HRA Process Step
Task 2 – Component Selection	**Identification** of previously existing HFEs & potential response to spurious actuations/indications
Task 5 – Fire-Induced Risk Model	**Identification and Definition** of fire response HFEs
Task 12 – Fire HRA	**Qualitative Analysis -** definition, context & performance shaping factors
Task 7 – First/Screening Quant.	**Quantification –** typically screening or scoping
Task 8 – Scoping Quantification	**Quantification –** typically scoping
Tasks 11/14 – Detailed Scenario Quantification	**Quantification & Dependency** could be screening, scoping or detailed HRA
Task 15 – Uncertainty	**Uncertainty**

Relationship of Detailed Fire HRA to FPRA Tasks*

- Detailed Fire HRA supports FPRA quantification
  - Developed, and typically used, for detailed fire scenarios
    - Detailed Fire Scenarios (Tasks 11 & 14)
    - Uncertainty/Sensitivity (Task 15)
  - But can be used at any level, such as:
    - Screening / First Quantification (Task 7)
    - Scoping (Task 8)
- Detailed Fire HRA uses inputs from most, prior FPRA tasks
  - Identification & Definition of HFEs (Tasks 2, 5, 7 & 8)
  - Qualitative Analysis (Task 12 – Fire HRA)

*** All task numbers refer to NUREG/CR-6850; EPRI 1011989**

PRA Standard Requirements for HRA Quantification

Relevant HLRs from Internal-Events Section (Ch. 2)

HLR-HR-G (from the internal events HRA element)

The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self consistent process that addresses the plant-specific and scenario-specific influences on human performances, and addresses potential dependencies between human failure events in the same accident sequence

Relevant HLRs from Fire Section (Ch. 4 of Standard)

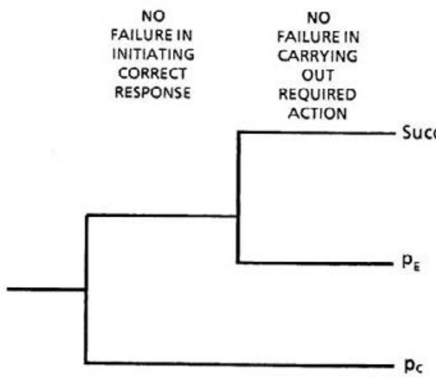
HLR-HRA-C (from the Fire HRA element)

The Fire PRA shall quantify HEPs associated with incorrect responses accounting for the plant-specific and scenario-specific influences on human performance, particularly including the effects of fire

EPRI Quantification Methods

- CBDTM (Cause Based Decision Tree Method)
  - 8 Decision trees based on simulator experiment insights
  - Default method for cognitive portion (detection/diagnosis)
- HCR/ORE Correlation (Human Cognitive Reliability / Operator Reliability Experiment)
  - Used for time-critical operator actions
  - Normalized time reliability correlation (function of $T_{available}$ / $T_{required}$)
- THERP (NUREG/CR-1278) for execution
- Methods are implemented in EPRI *HRA Calculator*® software, but can be quantified on paper

Post-Initiator HFE Representation: EPRI TR-100259



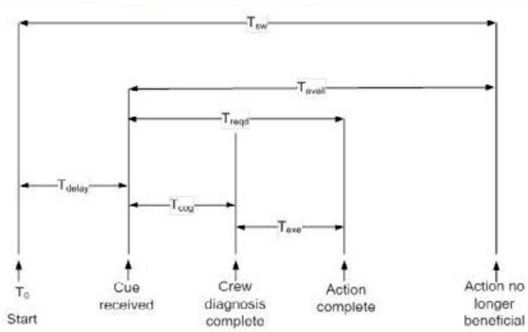
Pe = Execution is quantified using THERP

Pc = Cognitive is quantified using

CBDTM (default)

HCR/ORE (time critical HFEs)

EPRI Timeline for a Post-initiator HFE



T_0 = Start Time usually the initiating event

T_{sw} = System time window

T_{delay} = Time from start until cue

T_{exe} = Execution time (includes transit, tools, PPE & component manipulation)

T_{cog} = Cognition time (consists of detection, diagnosis, & decision-making)

T_{avail} = Time available = ($T_{sw} - T_{delay}$)

T_{reqd} = Time required for response = ($T_{cog} + T_{exe}$)

T_{delay} = Time from start of transient until cue is reached

T_{exe} = Execution time (expansion of EPRI T_m component manipulation for fire)

T_{cog} = Cognition time (when HCR/ORE is used = $T_{1/2}$)

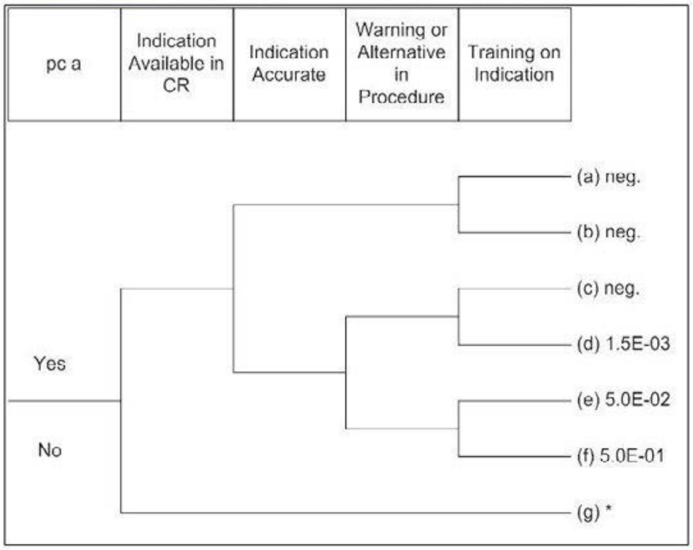
CBDTM Overview – Cognitive Method

- Analytical approach based on identification of failure mechanisms and compensating factors
- Applicable to rule-based behavior, such as when procedures are used
- Two high-level failure modes:
  - Plant information-operator interface failure
  - Operator-procedure interface failure
- Each failure mode is decomposed into contributions from several distinct failure mechanisms
- Default method, especially if not time-critical

CBDT - Summary of Failure Mechanisms

Type	Designator	Description
Failures in the Operator–Information Interface	p_c a	Data not available
	p_c b	Data not attended to
	p_c c	Data misread or miscommunicated
	p_c d	Information misleading
Failures in the Operator-Procedure Interface	p_c e	Relevant step in procedure missed
	p_c f	Misinterpret instruction
	p_c g	Error in interpreting logic
	p_c h	Deliberate violation (not sabotage)

CBDTM decision tree: pc-a Data not available

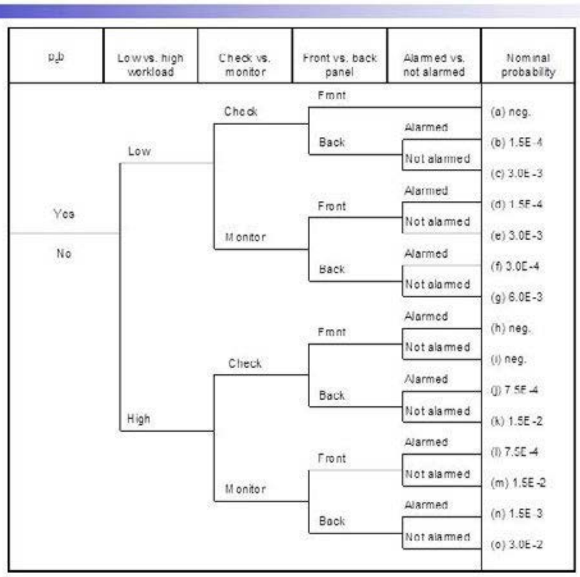


Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 15

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree: pc-b Data not attended to

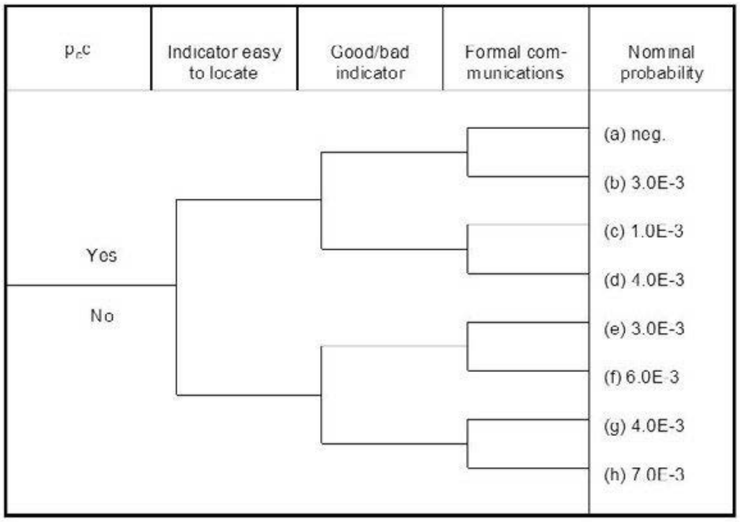


Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

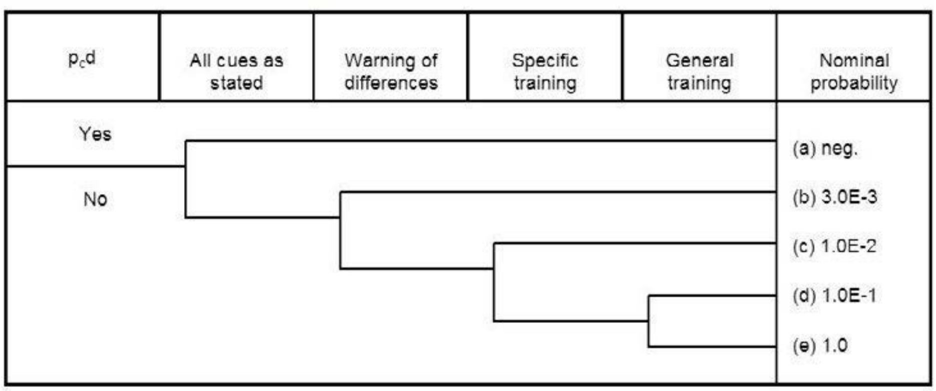
Slide 16

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

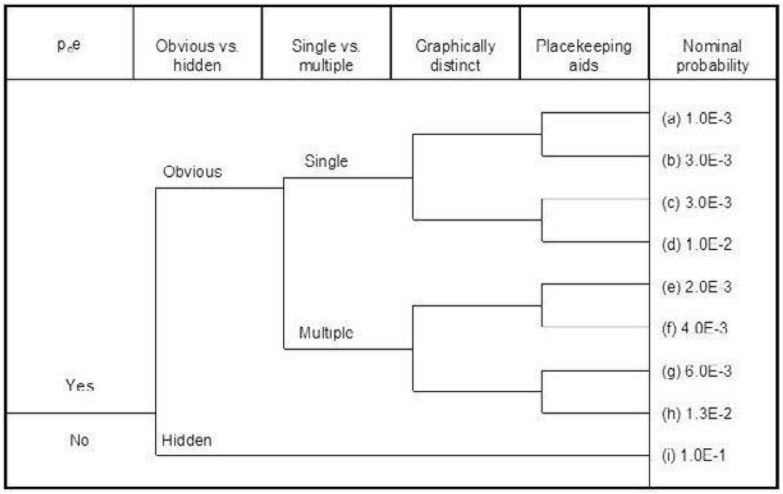
CBDTM decision tree:
pc-c Data misread or miscommunicated



CBDTM decision tree:
pc-d Information misleading



CBDTM decision tree:
pc-e Relevant step in procedure missed

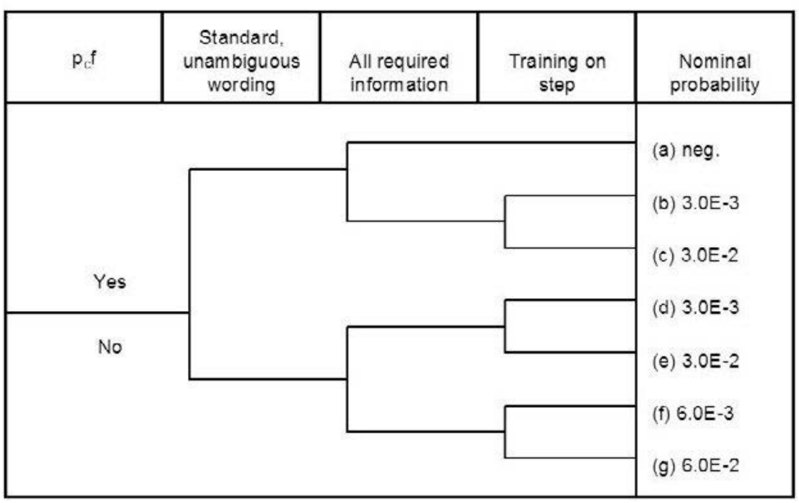


Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 19

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree:
pc-f Misinterpret instruction

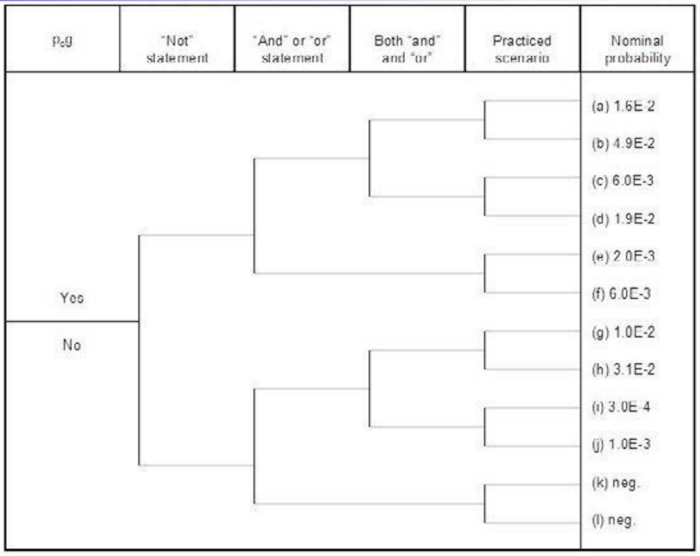


Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 20

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree:
pc-g Error in interpreting logic

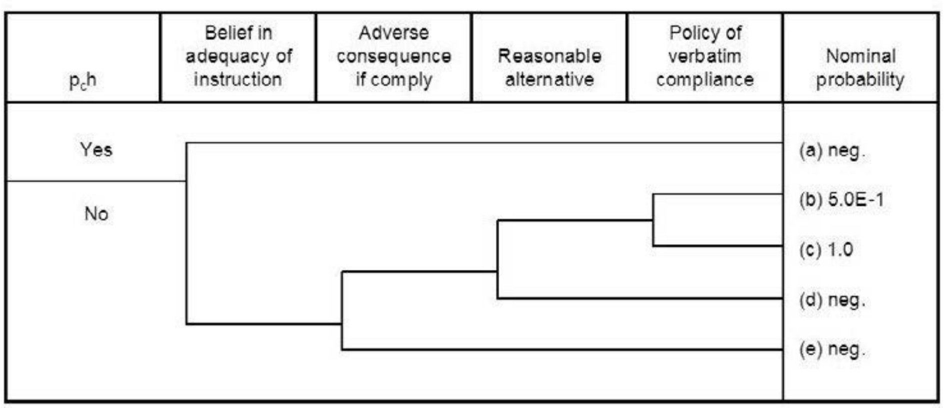


Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 21

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree:
pc-h Deliberate violation



Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 22

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Post-Initiators: CBDTM Recovery Factors

Tree	Branch	Self-Review	Extra Crew	STA Review	Shift Change	ERF Review
Pca	all	NC	0.5	NC	0.5	0.5
Pcb	all	X	NC	X	X	X
Pcc	all	NC	NC	X	X	X
Pcd	all	NC	0.5	X	X	0.1
Pce	a-h	X	0.5	NC	X	X
Pce	i	0.5	0.5	X	X	X
Pcf	all	NC	0.5	X	X	X
Pcg	all	NC	0.5	X	X	X
Pch	all	NC	X	X	NC	NC

CBDTM - Recovery Factors

Recovery Factor	Time Effective
Self Review	At any time there is a subsequent cue, other than the initial cue that would prompt the operator to revisit the decision OR Is there a procedural step that either returns the operator to the initial step where the error was made, or that repeats the initial instruction?
Other (Extra) Crew	At any time that there are crew members over and above the minimum complement present in the CR and not assigned to other tasks
Shift Technical Advisor	10 to 15 minutes after reactor trip.
Emergency Response Facility/ Technical Support Center	1 hour after reactor trip – if constituted
Shift Change	6 hours after reactor trip given 8 hour shifts 9 hours after reactor trip given 12 hour shifts

HCR/ORE Overview – Cognitive Method

- **Cognitive** modeling of **time-critical operator actions**
  - For example, less than 30 minute time window
- Empirical method, a **time-reliability curve**
- Fitted to successful response times
- Data points in which crews were totally on the wrong path not included in the fitting ("outliers")
- P_c therefore conditional on a correct decision, or the initial error was discovered in a timely manner
- Normalized time to be limited to time windows on which observations were made. Extrapolation not valid
- Guidance in **EPRI-TR100259**:
  - If P_c < 1E-02, use the CBDTM
  - If P_c believed to be conservative, use CBDTM

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 25

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

HCR/ORE – Equation

$$P_C = 1 - \Phi\left[\frac{\ln(\frac{T_W}{T_{1/2}})}{\sigma}\right]$$

- ***P_C* = Probability of cognitive non-response**
- σ = Logarithmic standard deviation (Determined based on cue response structure – next slide)
- Φ = Standard normal cumulative distribution
- $T_W = T_{SW} - T_{delay} - T_M$ = time window available for cognitive response
- $T_{1/2}$ = Crew median response time

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

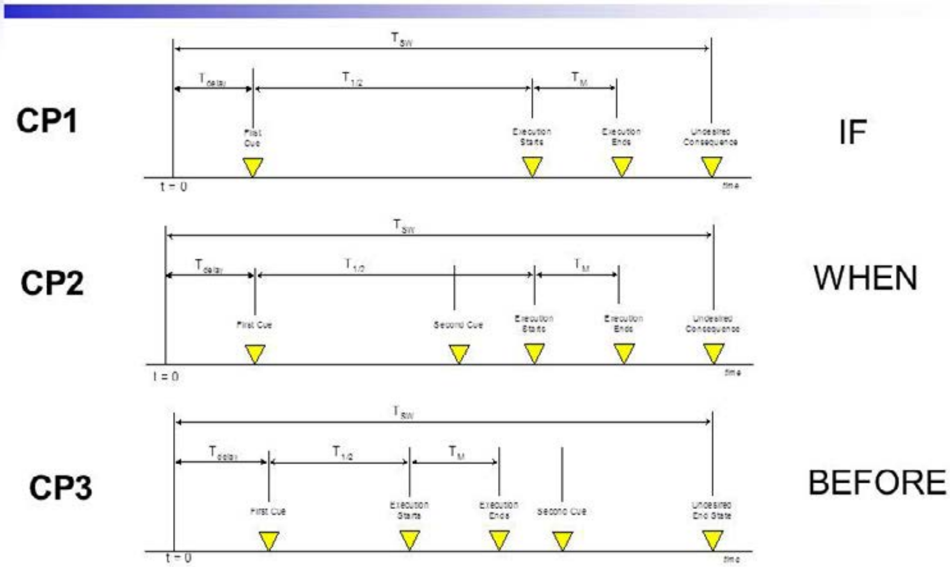
Slide 26

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

HCR/ORE - Sigma Values based on cue-response structure

Plant Type	Cue-Response Structure	Values for σ		
		Average	Upper Bound	Lower Bound
BWRs	CP1	0.70	1.00	0.40
	CP2	0.58	0.96	0.20
	CP3	0.75	0.91	0.59
PWRs	CP1	0.57	0.88	0.26
	CP2	0.38	0.69	0.07
	CP3	0.77	*	*

Categorization of Type CP Actions



Quantification:
Fire HEPs for HFEs from the Internal Events PRA

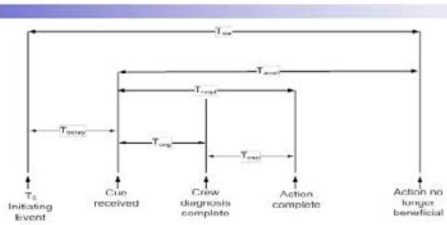
- If HFE has been quantified using EPRI HRA Approach for internal events, quantification for fire is a relatively simple modification in following areas:
  - **Timing**
  - **Cue** and indications impacts
  - Increase in **stress**
  - Increase in **workload**
  - Use of multiple **procedures**
  - For local actions, consider alternate **routes** if fire impacts the normal or ideal travel path

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 29

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire Impacts on Timing



T = 0 is considered the start of the fire – For existing HFEs T=0 is typically reactor trip. In most cases, the FPRA assumes the fire and reactor trip coincide.

T_{delay} = Time from start of transient until cue is reached. If the cue is considered to be procedure step the **fire may cause delays in the procedure implementation**.

T_{cog} = If the fire impacts some but not all of the **instrumentation** T_{cog} will be increased from the internal events case to account for the time required for the operators to asses the situation & determine which instrumentation is correct or diagnose based on secondary cues.

T_{exe} = For **main control room** actions in which there is no fire in the control room, T_m is considered to be the **same for the internal events case and the fire case**.

For **local actions, T_m will account for any detours caused by the fire**. T_m must also account for PPE & tools.

Fire PRA Workshop, 2012, Bethesda, MD
Task 12: Fire HRA – EPRI Detailed Analysis

Slide 30

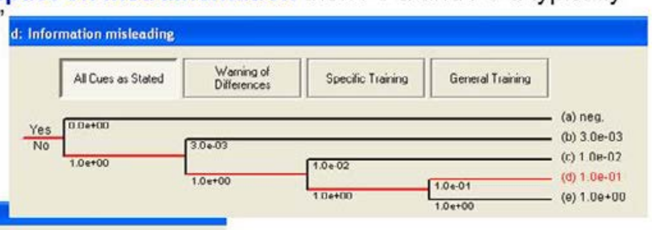
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

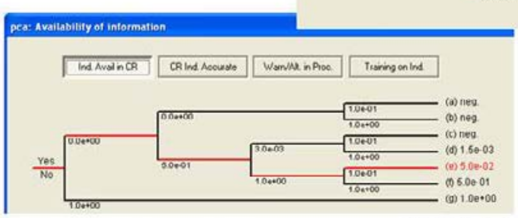
Fire Impacts on Timing (cont'd)

- If time available for recovery is reduced due to fire impacts on timing, then the recoveries previously credited in the internal events PRA within the CBDTM are to be revisited
- If time-critical action and cues/indications are impacted, then consider using upper bound for sigma when applying HCR/ORE

Fire Impacts on Instrumentation

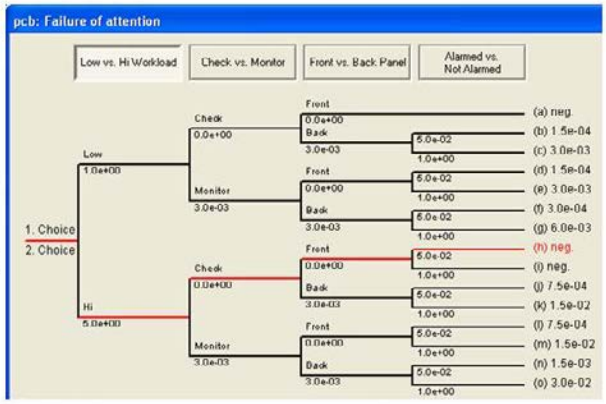
- If all **instrumentation is impacted** and there are no cues for diagnosis then HEP =1.0
- **Partial instrumentation** impacted is modeled in decision tree **Pc-a & Pc-d** (HEP range 1E-2 to 1.0)
- If the fire causes **no impact on instrumentation** then Pc-a and Pc-d typically evaluate to "Negligible"





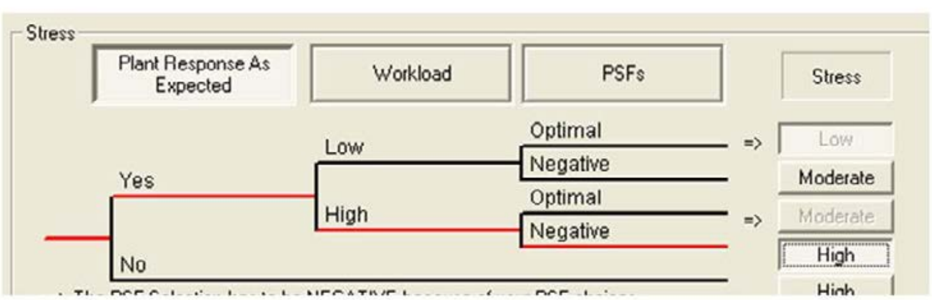
CBDT Example - Fire Impacts on Workload (Pc)

- Increased workload:
  - modeled explicitly
  - decision tree Pc-b
  - if fire causes increase in workload
  - select **High workload**
  - part of the cognitive phase (detection & diagnosis)
  - potentially recover if have additional staff



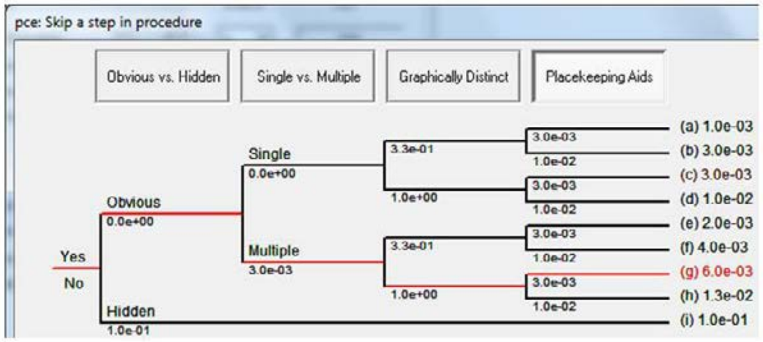
CBDT Example - Fire Impacts on Workload (Pe)

- Increase in workload is reflected by an increase in stress



Fire Impacts on Procedure Usage

- If EOPs are implemented in parallel to fire procedures, then multiple procedures are used
- If EOPs are suspended while fire procedures are being used, then only one procedure is credited and any time delays are accounted for in the timeline



Fire Impacts on Execution

- Stress is often increased from internal events case
  - Except for control room actions when operator actions occurring more than 70 minutes after the fire started, because
    1. 99% of fires are extinguished within 70 minutes per NUREG/CR-6850 Suppl. 1 (EPRI 1011259, Sept 2010)
    2. On average, a fire is extinguished in 13 minutes
- For local actions, an additional factor can be applied
  - Account for smoke, communication impacts, or
  - Additional equipment required by fire
    - Examples: SCBA, ladders, keys, tools

Fire Response HFEs

- Method selection depends on timing
  - CBDT approach to quantification applied first
  - HCR/ORE for time critical fire response actions
    - May use upper bound based on sigma value
- Ex-control room actions required due to loss of control are not substantially different from other local actions (e.g., during SBO) provided that local actions are not credited in close proximity to fire location
- No separate guidance for MCR abandonment
  - MCR typically is completely abandoned due to uninhabitability, not due to loss of control/functionality initial results show that frequency is low enough to not be a concern
    - If required, additional decision trees may be developed to model locus of control moving outside the control room

Fire Response HFEs

- Same considerations as internal events actions and the following **additional considerations**
  - **Ambiguously worded procedures**: Fire procedures are not standardized like EOPs. Modeled in decision tree $P_c f$. For internal events HFEs $P_c f$ typically evaluates to negligible.

  - **Local controls** may not be as easily accessible and as well trained on as for internal events actions. In this case, higher Error of Omission is selected from THERP
  - **No base case** from which to build the analysis, so entire analysis must be developed

Undesired Response to Spurious Indication or Actuation

- The following can be screened from consideration during identification:
  - Actions for which multiple indications are available for different parameters or via redundant channels
  - Actions that have a proceduralized verification step, if verification will be effective given the fire scenario

Quantification of Undesired Operator Responses to Spurious Signals

- HEPs for actions that do not screen from consideration are initially to be set to 1.0 (failed)
- EPRI approach to quantification
  - Assume the Error of Commission has occurred, then
  - Identify, define and quantify a recovery action

EPRI HRA Uncertainty

- For fire, the EPRI approach applies the same error factors (based on final HEP) as for internal events

HEP Error Factor		
HEP	Reference	EF
HEP < 0.001	THERP Table 20-20	10
HEP > 0.001	THERP Table 20-20	5
HEP > 0.1	Mathematical convenience	1

Detailed Fire HRA Summary

Consists of HRA tasks that develop human error probabilities (HEPs) for the modeled human failure events (HFEs)

- HEP used in FPRA quantification
- HEP development provides qualitative insights on results drivers

Uses most of the steps in the **HRA Process**:

1. Identification & Definition of HFE
2. Qualitative analysis – context & performance shaping factors
3. Quantitative analysis – **method selection** & quantification of HEP
    a) Screening
    b) Scoping
    c) Detailed HRA
        a) EPRI approach (CBDTM or HCR/ORE & THERP)
        b) ATHEANA
4. Provides input to subsequent Fire HRA tasks
    - Dependency analysis
    - Uncertainty analysis (HRA Calculator error factors are kept the same for fire HRA)

Course Overview

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and Definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
      a) EPRI Examples (See handouts)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

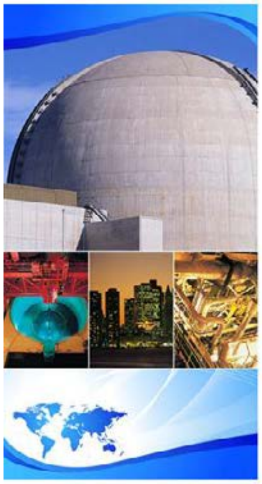
EPRI

CURTISS WRIGHT Flow Control Company
SCIENTECH

Sandia National Laboratories

SAIC® Science Applications International Corporation
From Science to Solutions™

3.9. Detailed Fire HFE Quantification Examples



EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 12 – Fire HRA
EPRI Approach to
Detailed Fire HFE Quantification
Examples

Jeffrey Julius (Scientech)
NRC-RES/EPRI Fire PRA Workshop 2013
Charlotte, NC

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples
Slide 1
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
      i. Theory
      ii. Example
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples
Slide 2
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

EPRI HRA Calculator™

- EPRI software was used, but is not required.
- EPRI HRA Calculator ™ version 4.1.1 was used for following examples.

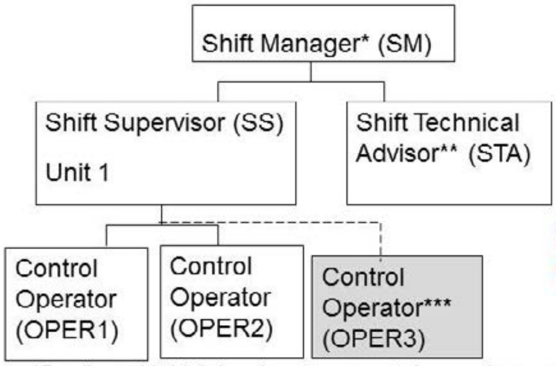
Assumptions for Examples

- Example Plant is a 2-loop Westinghouse PWR using Standard Westinghouse EOPs
- Fire PRA modeling is developed sufficiently
  - Detailed scenario descriptions and information available
- Fire Response Procedures
  - Implemented in parallel to the EOPs, and
  - Operators enter the fire procedures at the same time as they enter the EOPs
- Fire and reactor trip modeled to occur at the same time (T=0)

Crew Composition For Example Problems

- **Staffing**: Minimum staffing of the plant is as follows:

Inside Control Room:



Outside Control Room:

Local Plant Operators	Crew #
Auxiliary Operators	3
Turbine Hall Operator	2
Aux bldg/Water Treatment	2

Crew composition and titles are plant specific

*Dealing with high-level management issues (e.g., communicating with NRC)

**Can be outside CR. Will be in CR within 10 minutes of reactor trip.

***Normally available but not considered to be minimum staffing

Division of Labor During Fire Scenario

Following detection of fire, some crew members become members of the fire brigade and are unable to assist in actions directed by the control room. The fire brigade's only duty is to extinguish the fire.

Crew Member	Total Available Before Fire	# Assisting with fire*	# Available for EOP actions
Shift Manager	1	1	0
Shift Supervisor	1	0	1
STA	1	0	1
Control Room Operators	2	1	1
Plant operators	7	4	3

*This includes members of fire brigade and staff occupied with FPs or otherwise occupied due to the fire

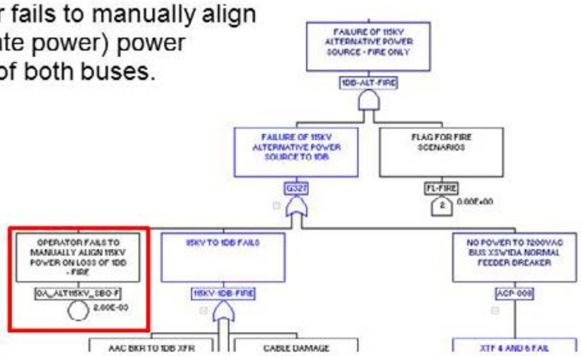
The EPRI approach reflects the plant practice that while the fire is ongoing no members of the fire brigade are available to assist with local or control room actions.

Generic Fire Response Timeline
(Plant-specific information may vary)

Time (Minutes)	
T=0	Fire causes reactor trip
T=0	Control room receives fire alarm and actives fire brigade Control room sends local operator to investigate fire
T=5	Control room starts implementing fire procedures in parallel to EOPs
T=10	Fire brigade is expected to be assembled and fighting fire within 10 minutes of activations
T=15	Emergency Response Facility (ERF) staffed and unusual event declared. Typical, plant policy states that if a fire is not under control within 15 minutes must declare unusual event.
T=70	Fire is out 99% of all fires are extinguished per FAQ 50

Example 1 - Operator fails to manually align 115kV bus (SBO)

- **Initial Conditions**:
- Steady state, full power operation.
  - Minimal staff on shift.
  - No out-of-service safe shutdown equipment.
- **Initiating Event**: Fire in turbine hall causes SBO
- **HFE:** Operator fails to manually align 115kV (alternate power) power following loss of both buses.



Accident Sequence & Success Criteria

Accident Sequence

- Fire causes reactor trip
- Reactor trip and turbine trip successful.
- AFW failed due to the fire.
- PORV spuriously opens due to the fire.
- The Main Generator breaker opens and the BOP buses are powered through XTF0001 (reverse) and XTF0002.
- EDG B starts and the Engineered Safety Feature (ESF) Loading Sequencer loads onto bus.
- EDG B trips due to fire damage. The ESF Loading Sequencer is still sending a signal to trip the normal and alternate feeder breakers (for EDG protection) to the bus.
- All diesels failed – SBO
- DC power remains available until batteries deplete. Batteries will last for 4 hrs

Operators Success Criteria

- Locally trip the alternate feeder breaker by removing power from the ESFLS to remove the trip open signal.
- Energize XSW1DA or 1DB from the alternate power source.

Consequence of failure: Core damage due to stuck open PORV

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 9

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Expected Crew Response

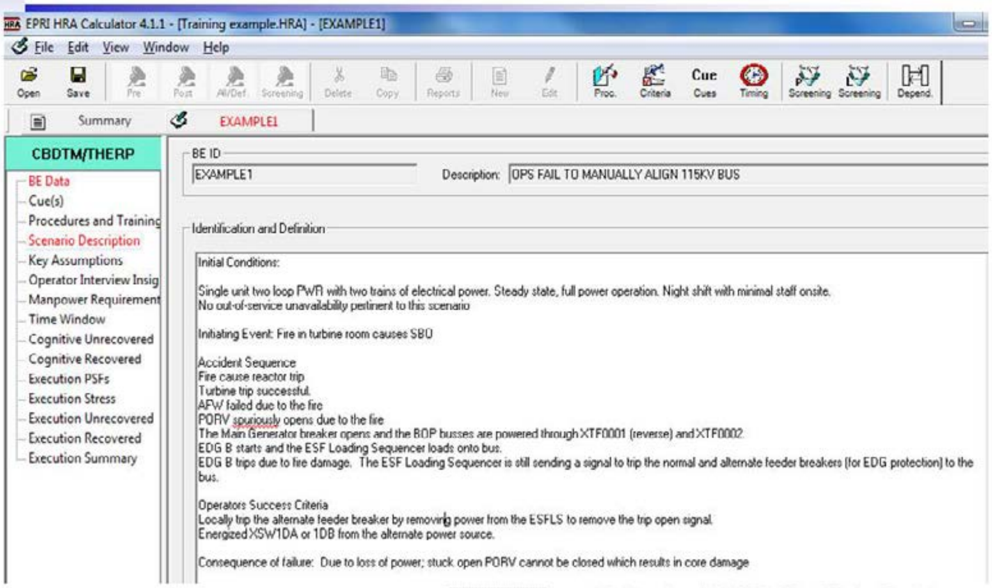
Time	Event	Comment
T=0min	Fire and Reactor Trip	
T=0min	Control Room dispatches fire brigade to fight the fire; immediate memorized actions (steps 1-3 EOP 0) performed	Fire brigade comprised of 3 Local Plant Operators
T=3min	EOP 0, step 3 indicates SBO. Procedure transition brief held by SS to alert all control room staff that they have an SBO and fire. They will be entering ECA 0.0	OPER1 designated to perform ECA 0.0; OPER2 designated to start reviews of fire procedures
T=5min	OPER1 begins ECA 0.0	
T=7min	Step 4 ECA 0.0 dispatch local plant operator to investigate failure of AFW	Assume this Local Plant Operator will be tied up restoring AFW and not available to assist in additional actions
T=10min	STA arrives	Begins monitoring critical safety functions
T=15min	OPER1 reaches step 10 ECA 0.0, notifies SS that they need to transition to AOP 304	By this time OPER2 has finished reading through fire procedures
T=15min	SS briefs control room staff on the AOP coordination with the fire procedures	7 contingent time critical action (need in the first hr) in fire procedure; 2 necessary. Confirmed: fire procedure actions will not interfere with AOP actions; sufficient personnel available to do both in parallel. Late actions (>4hr) are postponed until SBO is recovered.
T=20min	OPER1 begins AOP 304; OPER2 begins directing fire procedure actions	OPER2 dispatches 1 local plant operator to perform fire procedure actions
T=35min	OPER1 arrives at step 17 of AOP 304 (locally remove power from ESFLS)	Cue for action

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 10

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

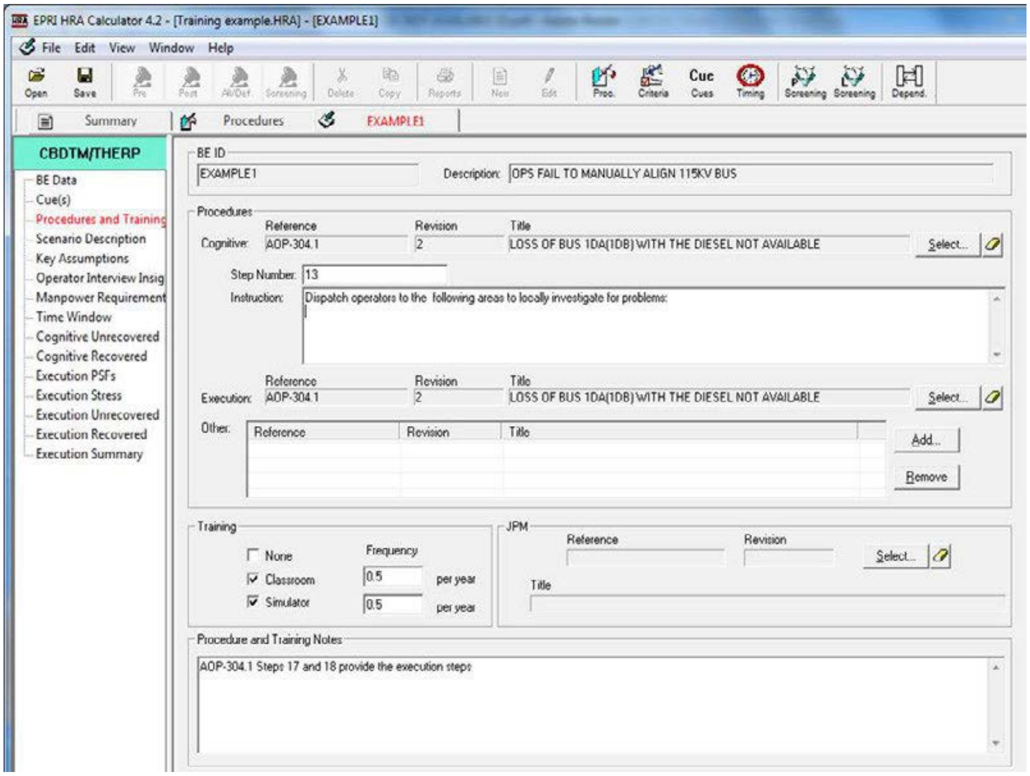
Scenario Description Using EPRI HRA Calculator

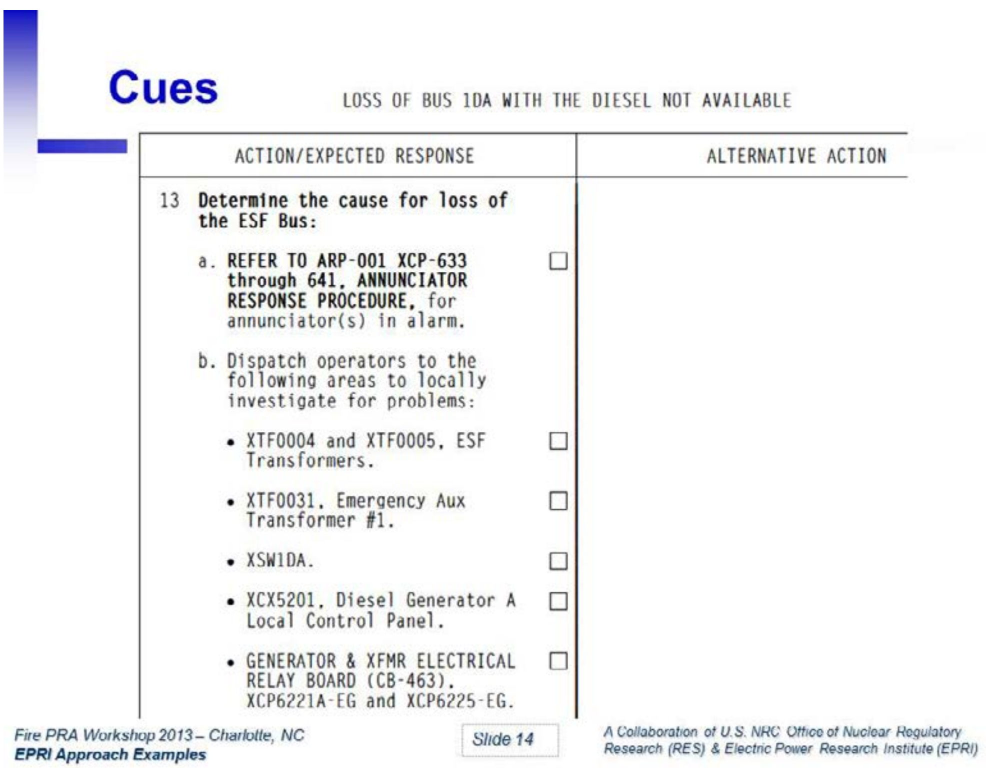


Procedures

- **Procedures**:
  - Upon Reactor Trip, enter EOP-0
    - Step 3 of EOP-0 verifies that buses are energized. Buses are de-energized; this will take the operator to ECA 0.0 [Station Blackout Procedure]
    - Step 10 of ECA 0.0 checks that buses 1DB and 1 DA are energized. Both buses are de-energized; this will take the operator to AOP 304 due to loss of bus with no EDG.
    - Steps 17 and 18 of AOP 304 are the relevant response actions for this HFE:

ACTION/EXPECTED RESPONSE	ALTERNATIVE ACTION
17 **Locally remove power from the Train A ESF Loading Sequencer (XPN-6020 CB-436).** ☐	
18 **Energize XSW1DA from the normal power source:** a. Ensure BUS 1DA XFER INIT Switch is in OFF. ☐ b. Close BUS 1DA NORM FEED Breaker. ☐ c. Verify BUS 1DA potential lights are energized. ☐	18 <u>IF</u> XSW1DA normal power source is <u>NOT</u> available, <u>THEN</u> energize XSW1DA from the alternate power source: a) Ensure BUS 1DA XFER INIT Switch is in OFF. ☐ b) Close BUS 1DA ALT FEED Breaker. ☐ c) Verify BUS 1DA potential lights are energized. ☐


EPRI HRA Calculator 4.2 - [Training example.HRA] - [EXAMPLE1]
File Edit View Window Help
Open Save Pre Post All/Def Screening Delete Copy Reports New Edit Proc. Criteria Cues Timing Screening Screening Depend.
Summary
Procedures
EXAMPLE1
CBDTM/THERP
BE Data
Cue(s)
Procedures and Training
Scenario Description
Key Assumptions
Operator Interview Insig
Manpower Requirement
Time Window
Cognitive Unrecovered
Cognitive Recovered
Execution PSFs
Execution Stress
Execution Unrecovered
Execution Recovered
Execution Summary
BE ID
EXAMPLE1
Description: OPS FAIL TO MANUALLY ALIGN 115KV BUS
Procedures
Reference Revision Title
Cognitive: AOP-304.1 2 LOSS OF BUS 1DA(1DB) WITH THE DIESEL NOT AVAILABLE
Select...
Step Number: 13
Instruction: Dispatch operators to the following areas to locally investigate for problems:
Reference Revision Title
Execution: AOP-304.1 2 LOSS OF BUS 1DA(1DB) WITH THE DIESEL NOT AVAILABLE
Select...
Other: Reference Revision Title
Add...
Remove
Training
None
Classroom
Simulator
Frequency
0.5 per year
0.5 per year
JPM
Reference Revision
Title
Select...
Procedure and Training Notes
AOP-304.1 Steps 17 and 18 provide the execution steps


Cues
LOSS OF BUS 1DA WITH THE DIESEL NOT AVAILABLE
ACTION/EXPECTED RESPONSE
ALTERNATIVE ACTION
13 Determine the cause for loss of the ESF Bus:
a. REFER TO ARP-001 XCP-633 through 641, ANNUNCIATOR RESPONSE PROCEDURE, for annunciator(s) in alarm.
b. Dispatch operators to the following areas to locally investigate for problems:
• XTF0004 and XTF0005, ESF Transformers.
• XTF0031, Emergency Aux Transformer #1.
• XSW1DA.
• XCX5201, Diesel Generator A Local Control Panel.
• GENERATOR & XFMR ELECTRICAL RELAY BOARD (CB-463). XCP6221A-EG and XCP6225-EG.
Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples
Slide 14
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Cues

Cue(s)

Initial: Dispatch operators to the following areas to locally investigate for problems for XSW1DA [Select...]

Recovery: [Select...]

The cues for this HFE are straight forward however communication between control room and local operators will be impacted by the SBO and the fire.

The control room operators direct local operators to investigate for problems and then report back to the control room.

The travel pathways are not blocked by the fire

Degree of Clarity of Cues & Indications: ( ) Very Good (•) Average ( ) Poor

Comments:

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 15

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

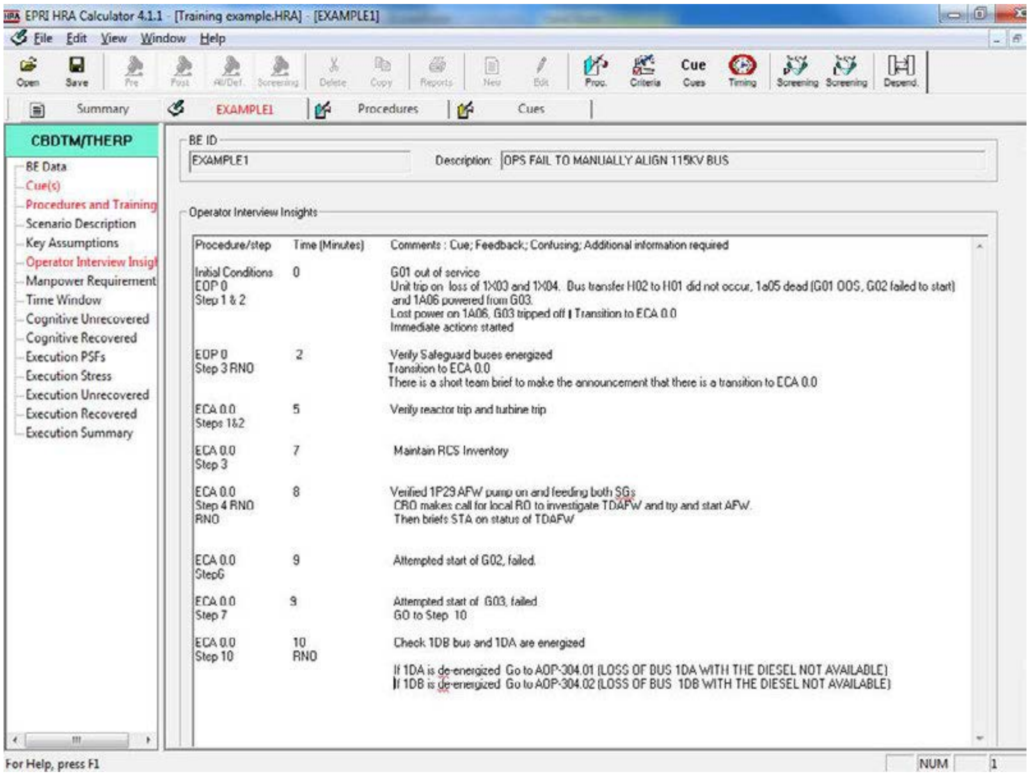
Simulator Observation (SBO non-fire scenario)

Procedure/step	Time (Minutes)	Comments : Cue; Feedback; Confusing; Additional information required
Initial Conditions	0	G01 out of service
EOP-0 Step 1 & 2	0	Unit trip on loss of 1X03 and 1X04. Bus transfer H02 to H01 did not occur, 1a05 dead (G01 OOS, G02 failed to start) and 1A06 powered from G03. Lost power on 1A06, G03 tripped off – Transition to ECA-0.0 EOP-0 Immediate actions started
EOP-0 Step 3 RNO	2	Verify Safeguard buses energized Transition to ECA 0.0 There was a short team brief to make the announcement that there was a transition to ECA 0.0
ECA-0.0 Steps 1&2	5	Verify reactor trip and turbine trip
ECA-0.0 Step 3	7	Maintain RCS Inventory
ECA-0.0 Step 4 RNO	8	Verified 1P29 AFW pump on and feeding both SGs CRO makes call for local RO to investigate TDAFW and try and start AFW. Then briefs STA on status of TDAFW
ECA-0.0 Step6	9	Attempted start of G02, failed.
ECA-0.0 Step 7	9	Attempted start of G03, failed – GO to Step 10
ECA-0.0 Step 10	10	Check 1DB bus and 1DA are energized RNO If 1DA is de-energized Go to AOP-304.01 (LOSS OF BUS 1DA WITH THE DIESEL NOT AVAILABLE) If 1DB is de-energized Go to AOP-304.02 (LOSS OF BUS 1DB WITH THE DIESEL NOT AVAILABLE)

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 16

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)



Timing

- T = 0 Start of fire and reactor trip
- T_{SW} = 90 minutes
  Time to core damage based on an IPE thermal hydraulic run for loss of AFW and a station blackout with one primary PORV stuck open.
- T_{delay} = 30 minutes from reactor trip unit operators reach step 13
  - Based on simulator observation for a similar scenario for SBO it took operators 10 minutes to get through ECA 0.0 step 10
  - Simulation based on non-fire SBO so an additional time has been added to account for fire impacts.
  - It is estimated that it will take about 10 minutes to reach step 13 of AOP-304
  - Tdelay=20+10 minutes
- T_{cog} = 10 minutes based on operator interviews. This is the time operators estimated it would take to locally investigate status of breaker.
  - This includes time for the SS and STA to confer, coordinate with the fire procedures, approve the action and communicate to control room operators to commence steps 17 and 18.

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 18

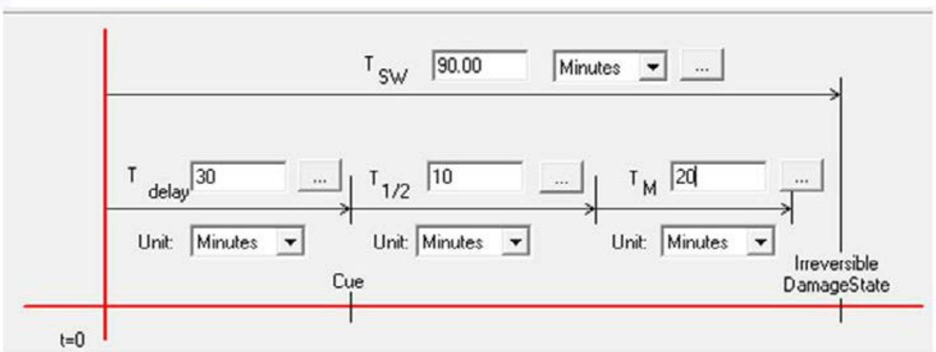
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Timing (cont'd)

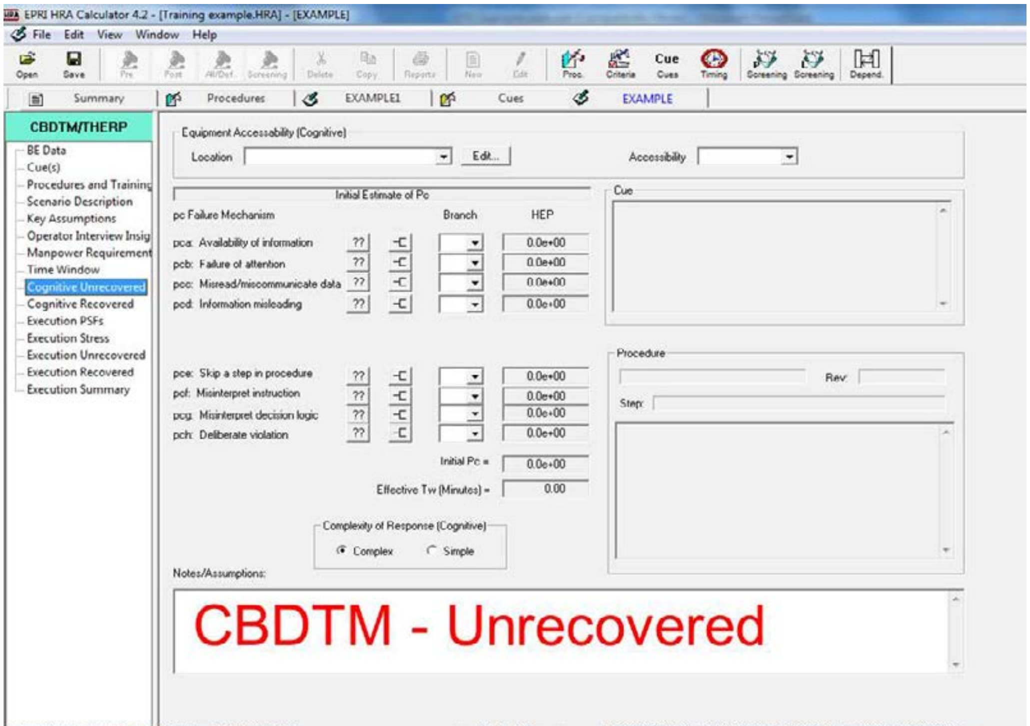
T_{exe} = 20 minutes

- The action to locally remove power from the Train B ESF Loading Sequencer is trained on using Job Performance Measure (JPM) 12654 – Align ALT Feed Breaker. This JPM has a time requirement to be able to complete the local portion of the actions within 15 minutes, and this has been verified by observations of the JPM. The timing starts once the operator is given the instructions to perform this action and ends once the MCR action had been complete (end of step 18).
  - As part of this JPM the operators train on putting on flash gear which is required to locally remove power from the Train B ESF Loading Sequencer. The flash gear is stored in a cabinet at the entrance to the relay room.
- After the operators complete the local action they will need to return to the control room to tell the control room operators they were successful. This additional travel time is expected to take 5 minutes.
  - Under ideal conditions the Local Plant Operator could use the phone to call the control room. However, for fire, no cable tracing was performed on the phone lines so the telephones are assumed to unavailable.
- T_{exe} = 15 minutes + 5 minutes = 20 minutes

Timeline



Based on timeline a moderate dependency is considered for recovery



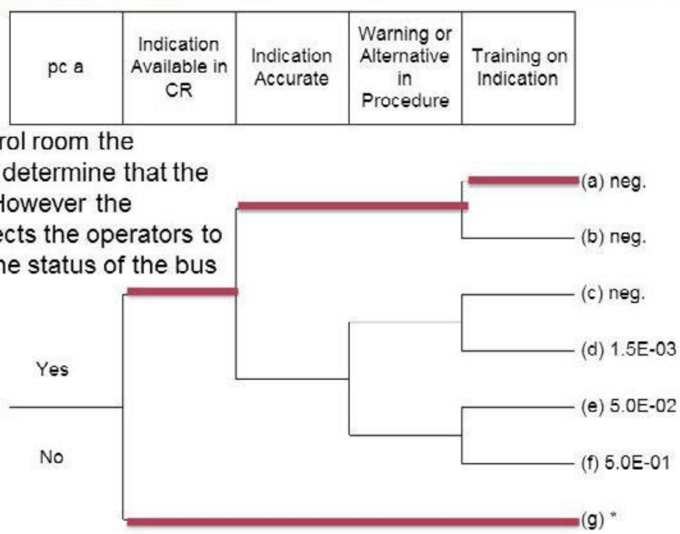
Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 21

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree: pc-a Data not available

From the control room the operators can determine that the bus is failed. However the procedure directs the operators to locally verify the status of the bus

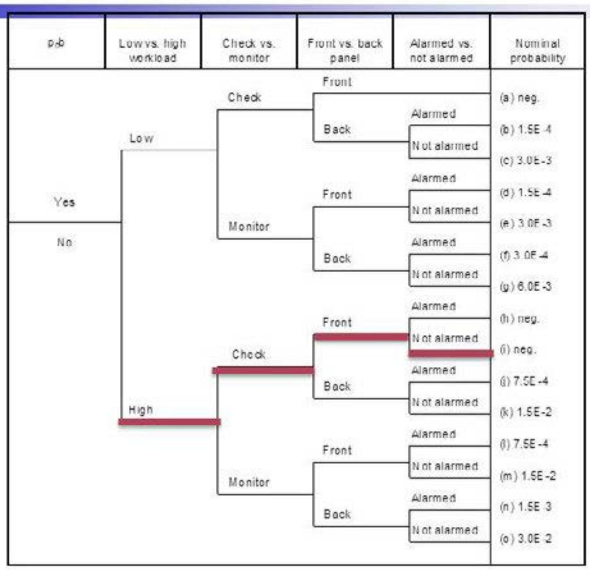


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 22

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree:
pc-b Data not attended to

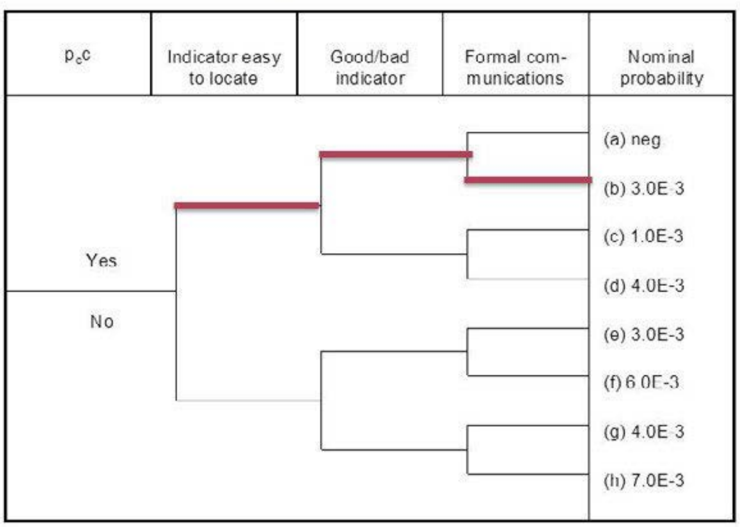


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 23

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree:
pc-c Data misread or miscommunicated

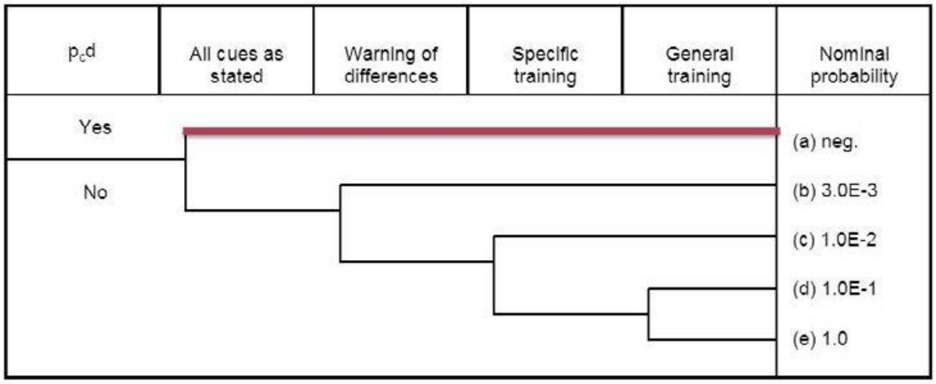


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 24

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree: pc-d Information misleading

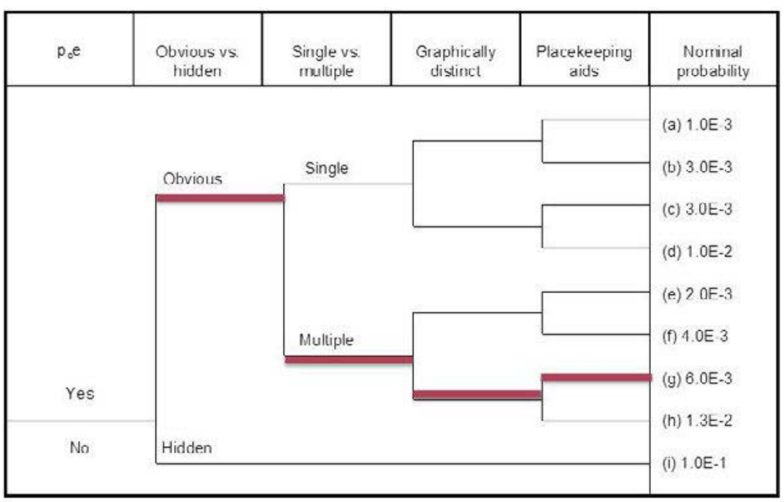


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 25

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree: pc-e Relevant step in procedure missed

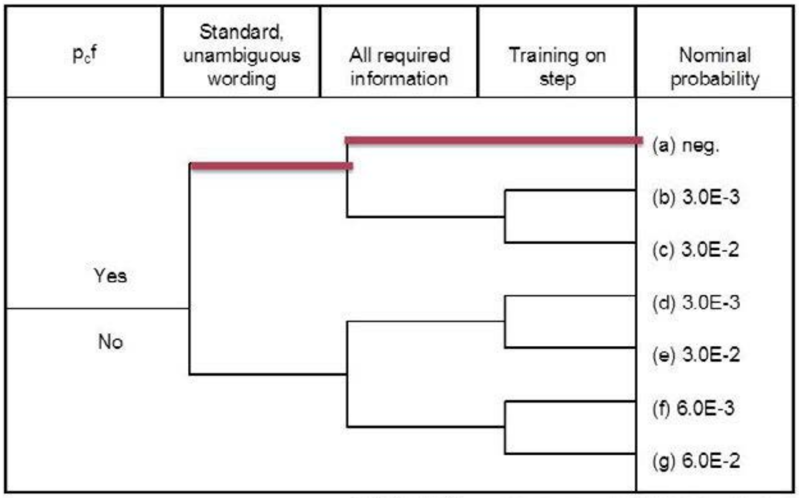


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 26

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree: pc-f Misinterpret instruction

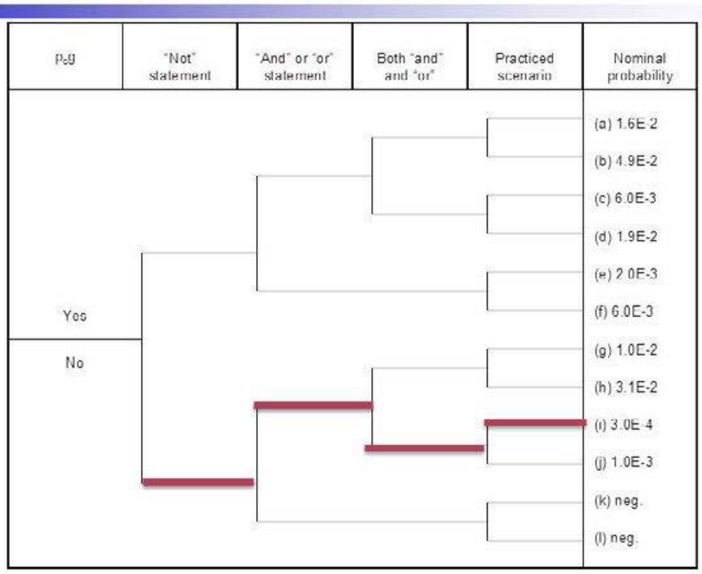


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 27

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree: pc-g Error in interpreting logic

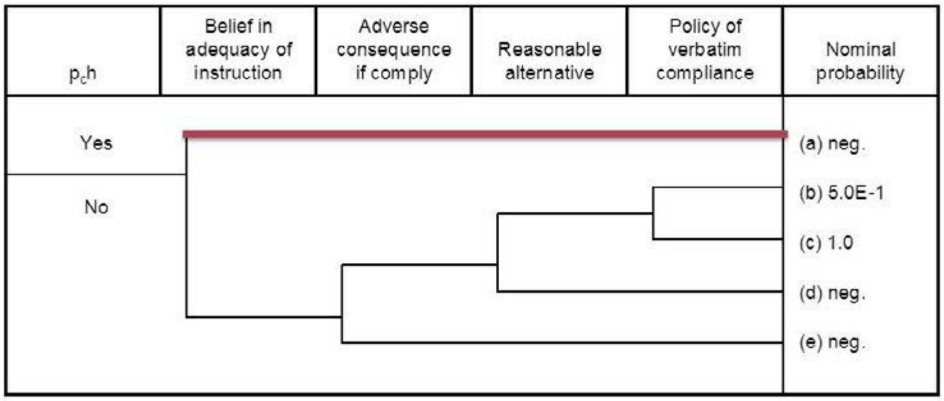


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

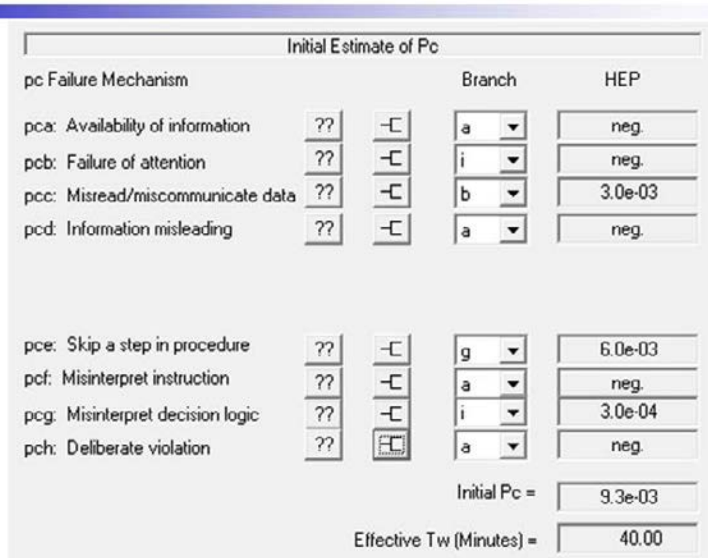
Slide 28

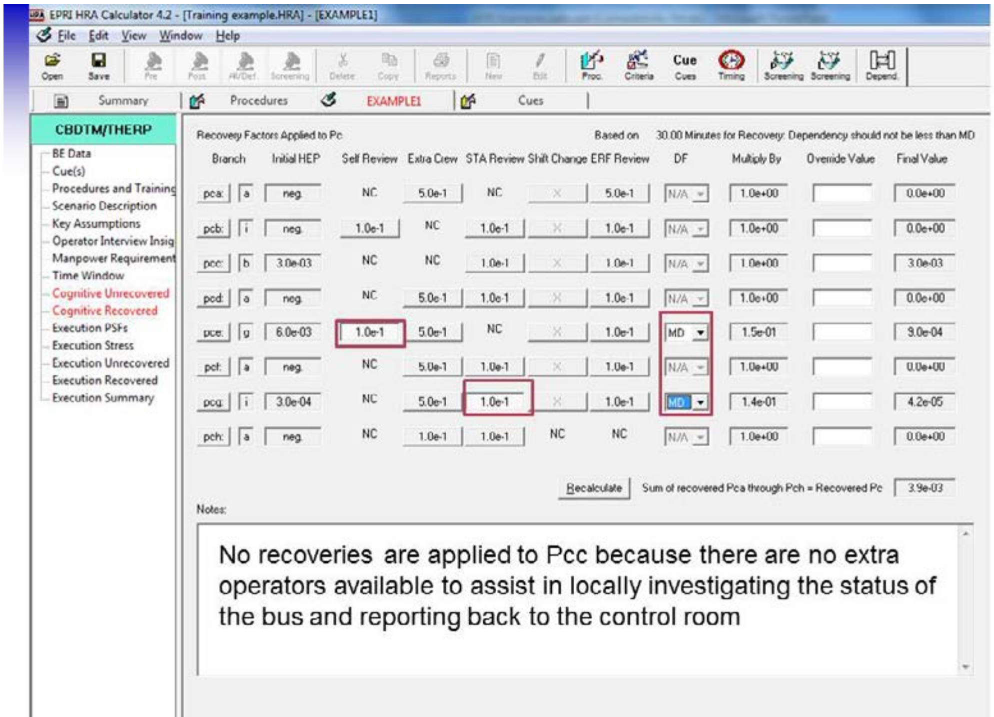
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree:
pc-h Deliberate violation



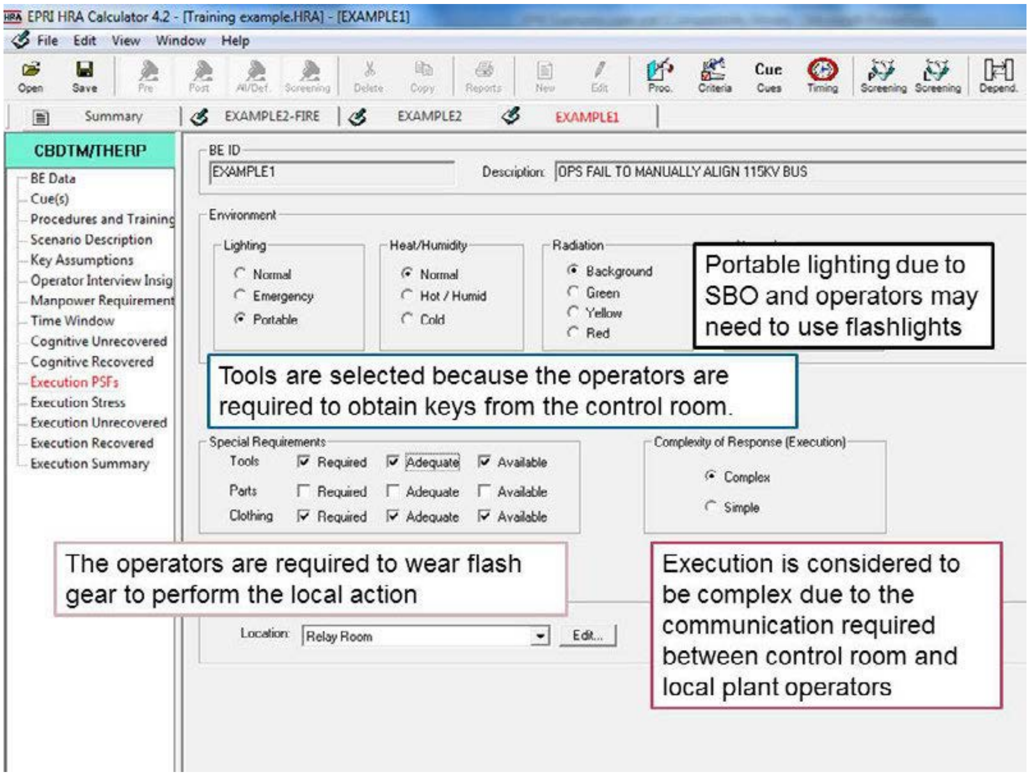
CBDTM Summary Unrecovered



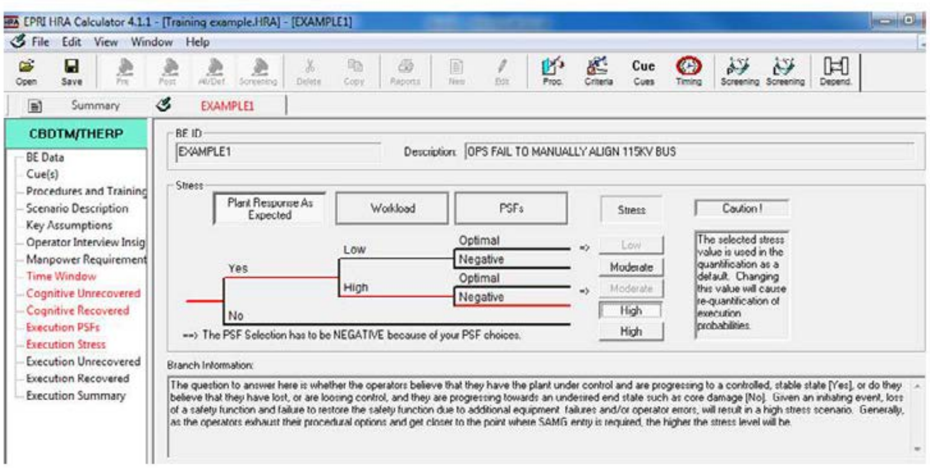


Execution PSFs

- **Environment:**
  - **Availability and Accessibility:** Given location of fire and layout of plant, the relay room is accessible and there is no degraded environment (e.g., no smoke) in the relay room or en route to the relay room.
  - **Visibility:** Given a SBO event, lighting will be significantly reduced (i.e., flashlights and/or emergency lighting).
  - **Communications:** Under ideal conditions the local plant operator could use the phone to call the control room. However, for the fire, no cable tracing was performed on the phone lines so the telephones are assumed to unavailable.
  - **Heat/Humidity**: Normal – fire effects do not reach this area, however, after some time (>action window) there could be a rise in temperature due to SBO.
- **Special Requirements**:
  - Operators are required to wear flash gear to locally remove power from the Train A ESF Loading Sequencer.
  - Operators will need key to access relay rooms due to loss of power all doors will be locked.



EPRI Stress Decision Tree



Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 34

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

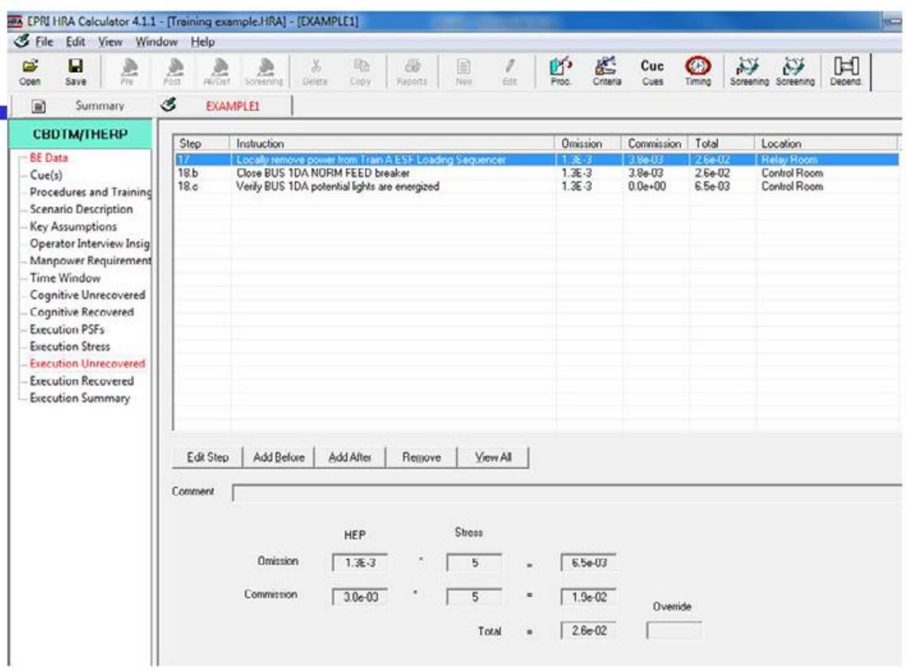
Critical Steps (Execution)

- LOCALLY Reset ESFLS to clear trip signal
  - Plant Operator, stationed at or near the MCR, gets ESFLS panel key from the MCR and proceeds to the Relay Room
  - Dons flash gear
  - Opens left cabinet (~2ft from floor) and locally removes power from the loading sequencer
  - Alert control operator that the trip signal is clear and that break can closed from the control room
- Close Breaker in MCR
  - Ensure BUS 1DA XFER INIT Switch is in OFF
  - Close BUS 1DA ALT FEED Breaker
  - Verify BUS 1DA potential lights are energized

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 35

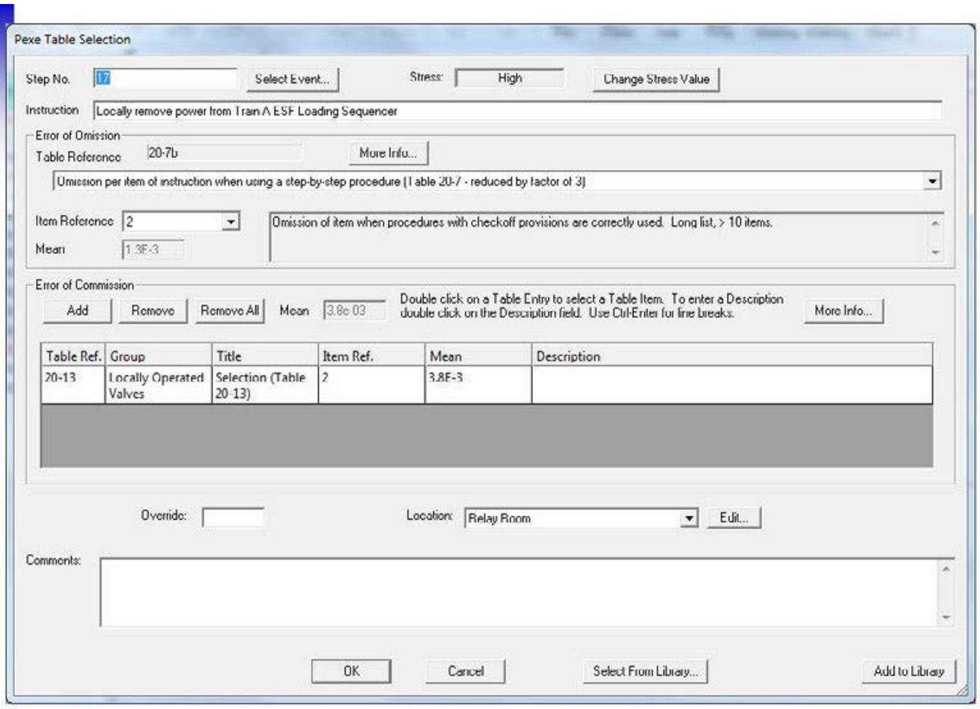
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)



Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 36

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

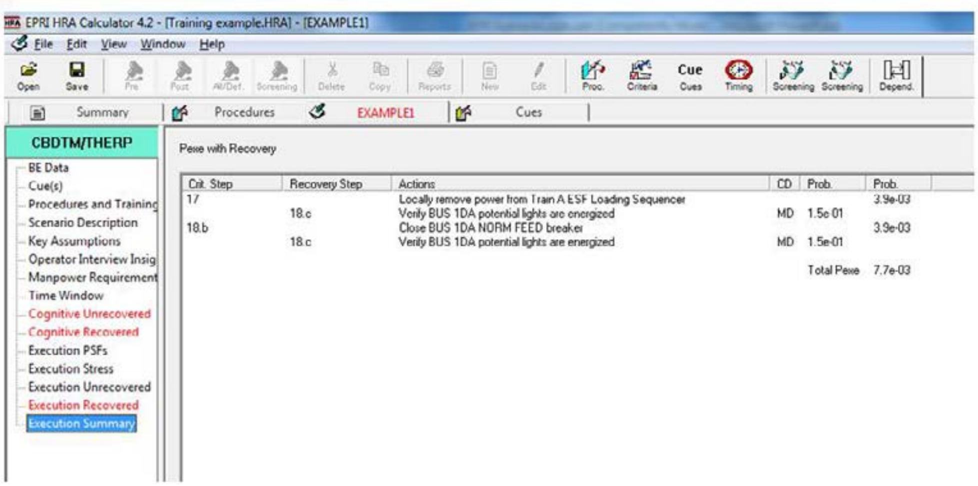


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 37

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Execution Summary

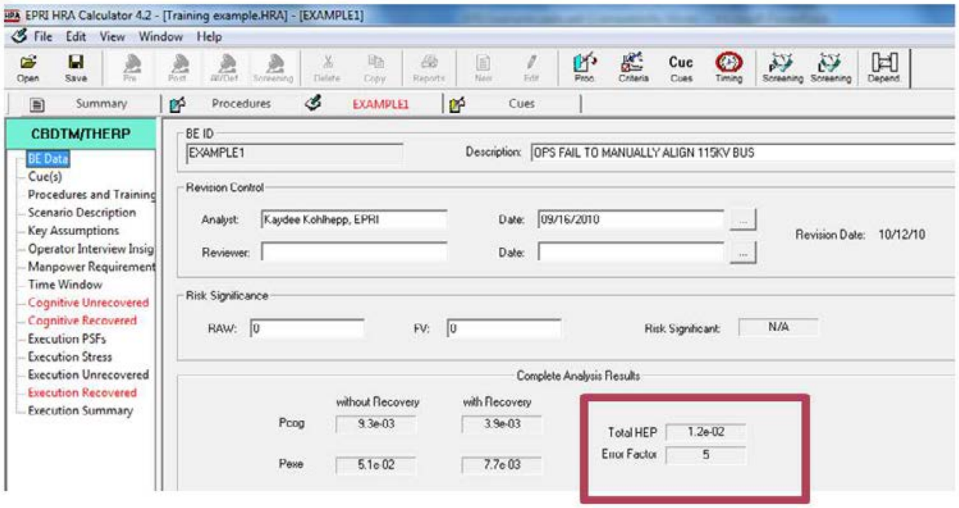


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 38

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Summary Results



Example 2

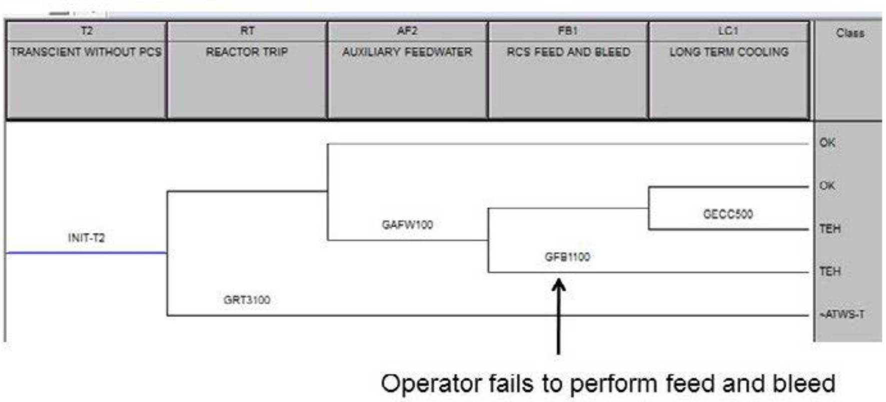
- Operators fail to perform feed and bleed during a fire
- For this example, the HFE has been quantified in detail for internal events

EXAMPLE2	Post				
Annunciator Response/THERP		2.7e-04	1.5e-03	1.7e-03	5
ASEP		7.7e-03	1.5e-03	9.1e-03	5
CBDTM/HCR Combination (Sum)		1.1e-03	1.5e-03	2.6e-03	5
CBDTM/THERP	X	1.1e-03	1.5e-03	2.6e-03	5
HCR/ORE/THERP		2.2e-10	1.5e-03	1.5e-03	5
Screening HEP		-	-	1.0e+00	1

Scenario Description

- **Initial Conditions**:
  - Steady state, full power operation. Night shift with minimal staff onsite.
  - No out-of-service unavailability pertinent to this scenario
- **Initiating Event**: Fire in turbine hall causes reactor trip.
  IE - TRANS
- **HFE:** Operators fail to perform feed and bleed (fire)
- **Fire Impacts:** The fire fails AFW, MFW and 2/4 SG level indicators in the control room.

Accident Sequence



Timeline

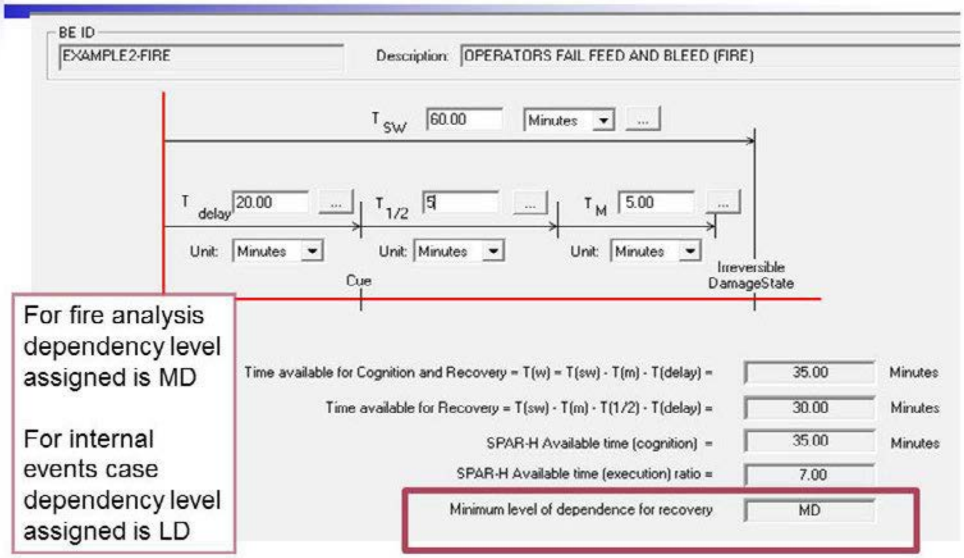
- T = 0 reactor trip and start of the fire
- T_{sw} = 60 minutes -time to SG dryout
- T_{delay}= 20 minutes -time to cue
- T_{exe} = 5 minutes - time to execute and procedurally verify execution steps. (Based on operator interviews)
- For internal events
  - T_{cog}=1 minutes (all cues and indications are accurate)
- For fire case with 2/4 SG levels impacted
  - T_{cog}=5 minutes to determine which SG levels indicators are accurate.

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 43

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Timeline



Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 44

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Procedure FR-H.1

UTILITY X
PWR

TITLE: **Response to Loss of Secondary Heat Sink**

NUMBER EOP FR-H.1
REVISION 25
PAGE 12 OF 28
UNIT 1

ACTION / EXPECTED RESPONSE	RESPONSE NOT OBTAINED
10. CHECK S/G Levels:	
a. S/G NR Level in at least one S/G - GREATER THAN 15% [25%]	a. IF Feedflow to at least one S/G verified, • WR Level increasing • Core Exit TCs decreasing THEN Maintain flow to restore S/G NR Level to GREATER THAN 15% [25%]. IF Feedflow NOT verified, THEN GO TO Step 11.
11. Check For Loss Of Secondary Heat Sink: WR S/G Level LESS THAN 15% in 2 S/G	Return to Step 1

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples
Slide 45
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Procedure FR-H.1

UTILITY X
PWR

TITLE: **Response to Loss of Secondary Heat Sink**

NUMBER EOP FR-H.1
REVISION 25
PAGE 13 OF 28
UNIT 1

ACTION / EXPECTED RESPONSE	RESPONSE NOT OBTAINED

****

CAUTION: Steps 12 through 18 must be performed without delay in order to establish RCS heat removal by RCS bleed and feed.

****

12. ACTUATE SI	
13. VERIFY RCS Feed Paths:	Manually start ECCS Pps and align ECCS Injection Valves to establish RCS feed path.
a. Check ECCS Pp status: • ECCS CCP - AT LEAST ONE RUNNING OR • SI Pps - AT LEAST ONE	IF An RCS feed path CANNOT be established, THEN Activate the monitor lights for monitor light Box C by turning the Monitor Test Light Switch to ON.
b. Verify ECCS valve alignment - PROPER EMERGENCY ALIGNMENT	Use White Status light to verify ECCS valve alignment.

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples
Slide 46
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Procedure FR-H.1

ACTION / EXPECTED RESPONSE	RESPONSE NOT OBTAINED
14. **RESET SI**	IMPLEMENT OP B-6B, LOCAL SI RESET.
15. **RESET Containment Isolation Phase A And Phase B**	
16. **ESTABLISH Instrument Air To Containment:**	
a. Open FCV-584	
b. Check Instrument Air Header Pressure GREATER THAN 90 PSIG, PI-380 (VB4 UNIT 1)	b. IMPLEMENT OP AP-9, LOSS OF INSTRUMENT AIR.
17. **ESTABLISH RCS Bleed Path:**	
a. Verify PZR PORV Block Vlvs - OPEN • 8000A for PCV-474 • 8000B for PCV-455C • 8000C for PCV-456	a. Restore power to block valves AND OPEN: 8000A: 52-1F-40 AND 52-1F-40R 8000B: 52-1G-46 AND 52-1G-46R 8000C: 52-1H-33 AND 52-1H-33R
b. Open all PZR PORVs	

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 47

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Fire Procedure

10/10/2010

SAMPLE PLANT (UNIT 1)
ATTACHMENT 7.3

Page 21 of 168

TITLE: Fire Protection of Safe Shutdown Equipment

4.0 Fire Area 3-BB (Continued)
Turbine Area, Elev. 115-ft

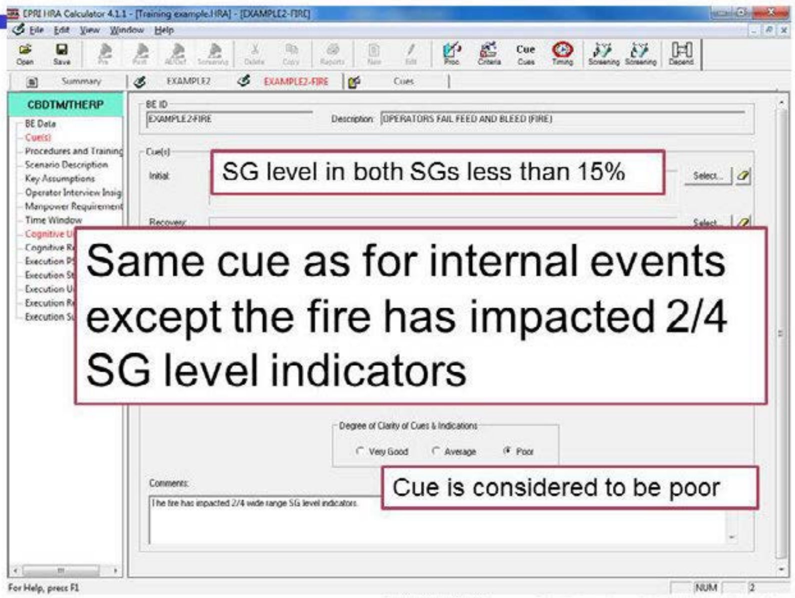
Affected Equipment	Available Equipment	Required Manual Action
6. MSS		
SG Level Indicators: SG 1-1: LT-516, -518, SG 1-2: LT-526, -528,	SG 1-1: LT-517, LT-519 SG 1-2: LT-527, LT-529	
SG Pressure Indicators: SG 1-1: PT-514, PT-515, PT-516 SG 1-2: PT-526	SG 1-1: All Available SG 1-2: PT-524, PT-525	
ADV: PCV-19, PCV-20,		Manually open valves after isolating supply air (normal, backup and nitrogen supply): PCV-19: AIR-I-1-4541 PCV-20: AIR-I-1-4350

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

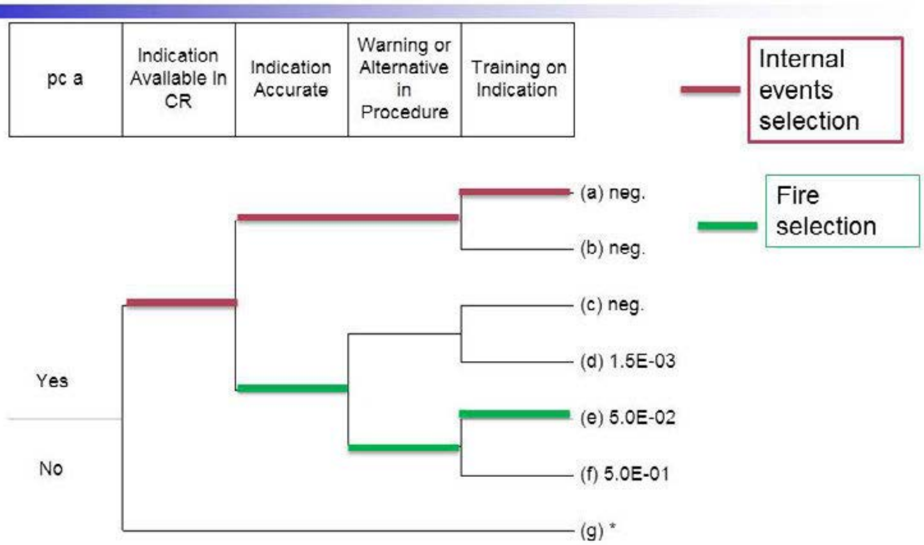
Slide 48

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

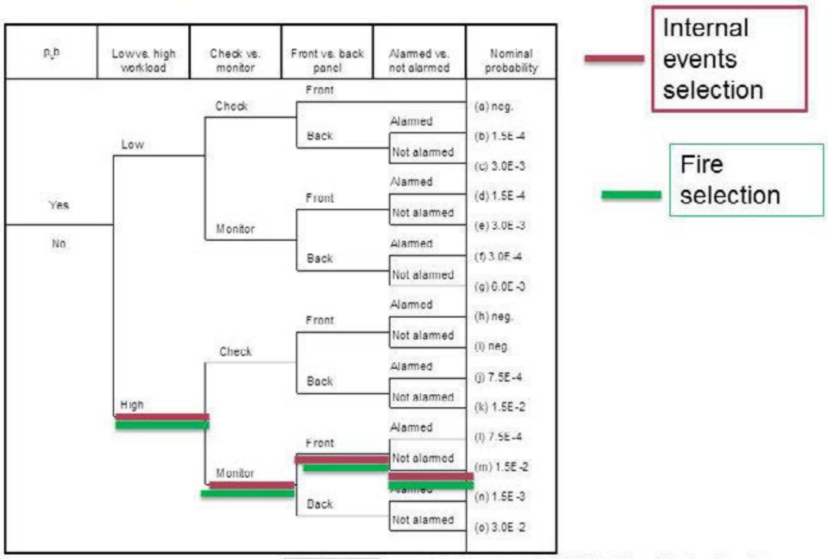
Cues and Indications



CBDTM decision tree: pc-a Data not available



CBDTM decision tree:
pc-b Data not attended to

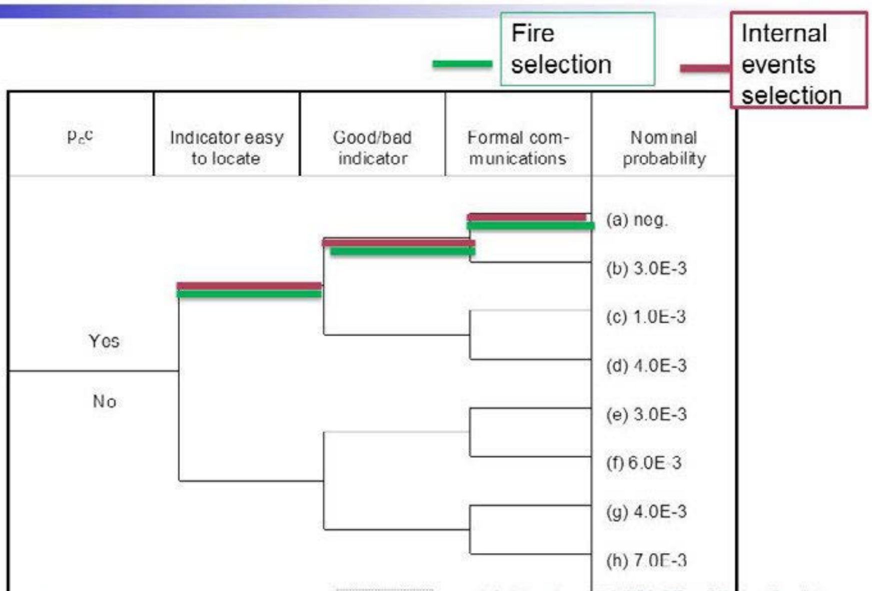


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 51

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree:
pc-c Data misread or miscommunicated

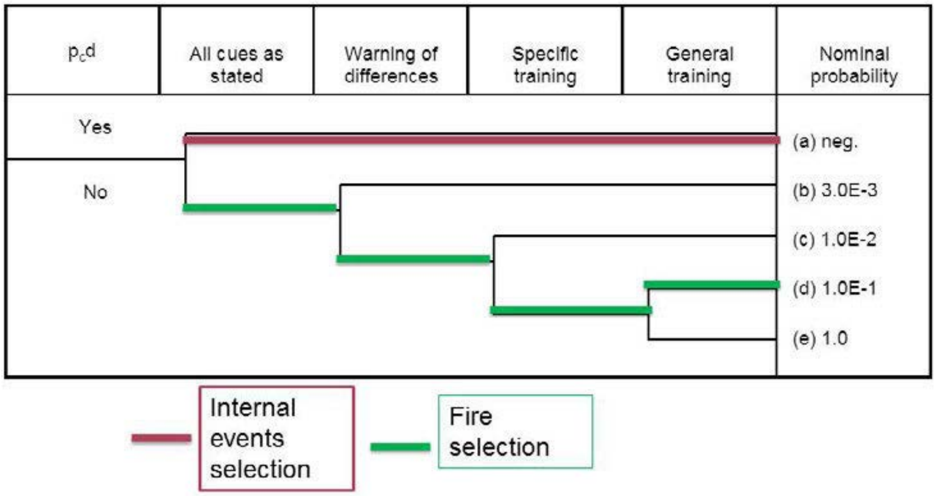


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 52

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree:
pc-d Information misleading

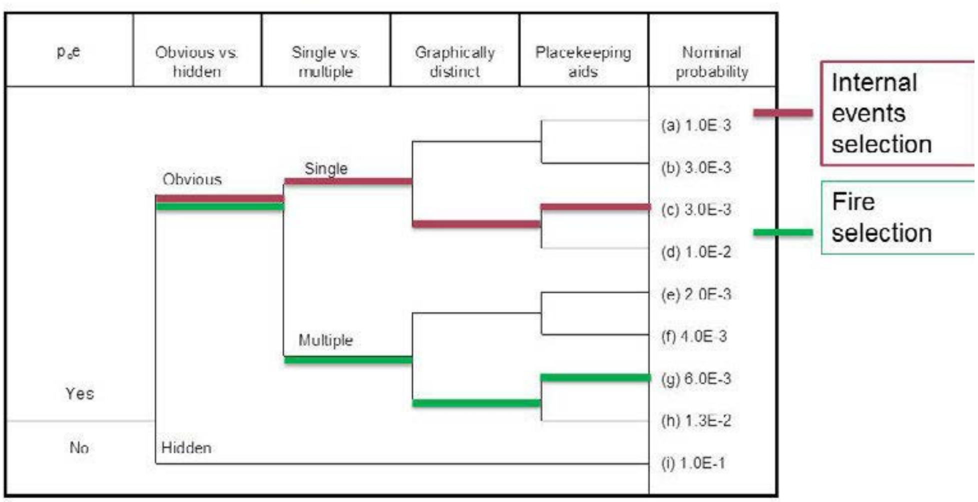


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 53

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

CBDTM decision tree:
pc-e Relevant step in procedure missed

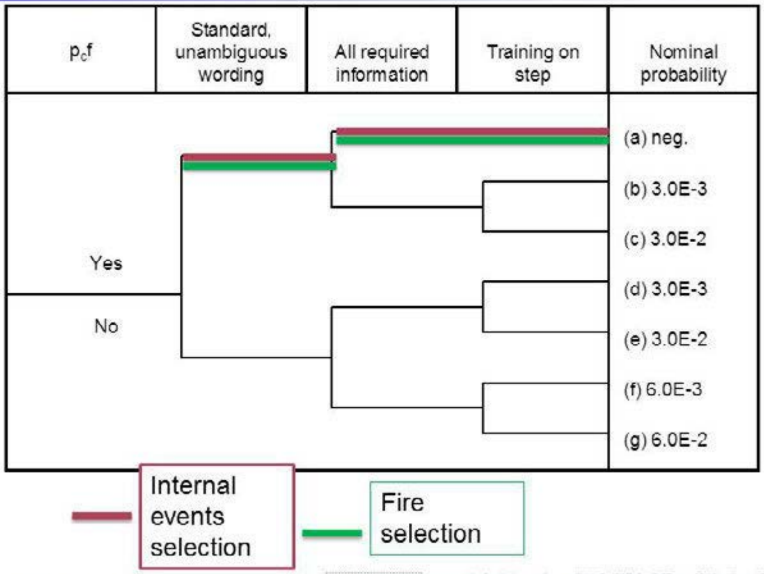


Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

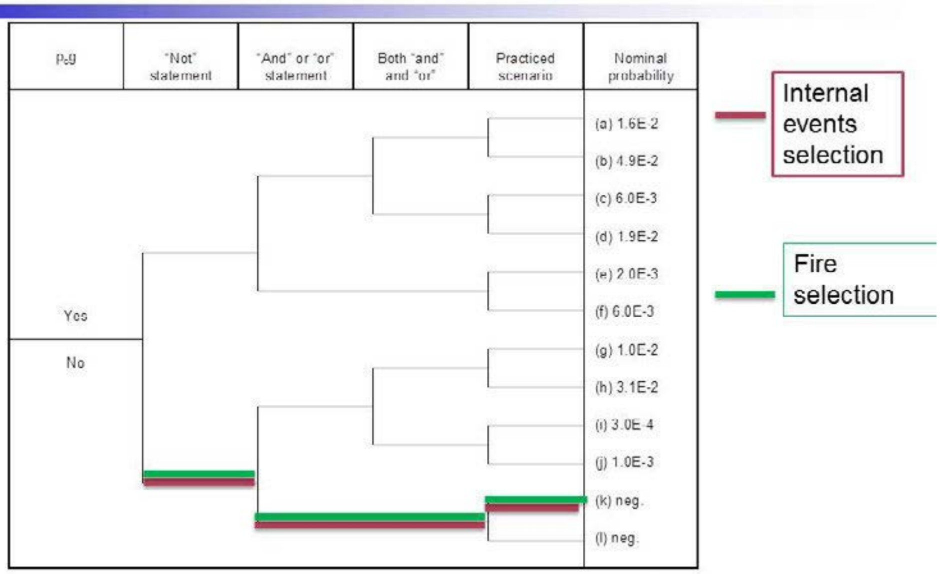
Slide 54

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

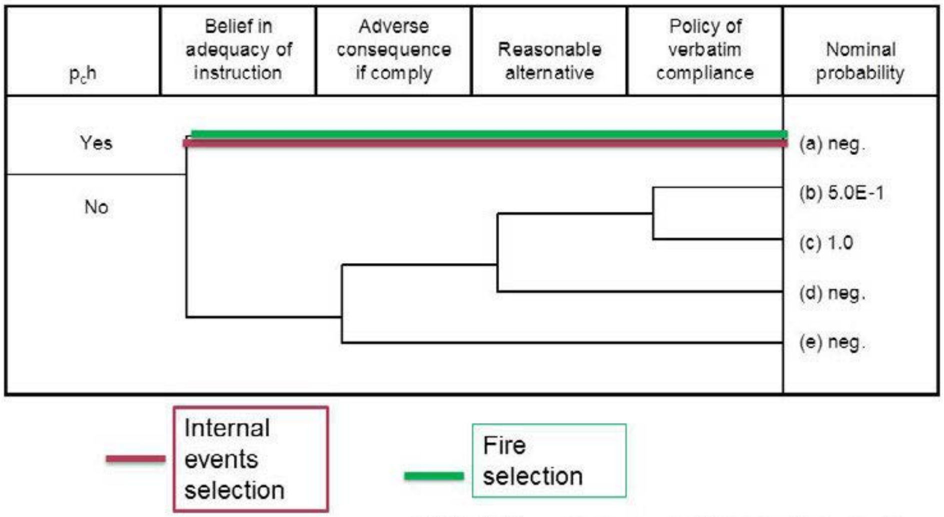
CBDTM decision tree: pc-f Misinterpret instruction



CBDTM decision tree: pc-g Error in interpreting logic



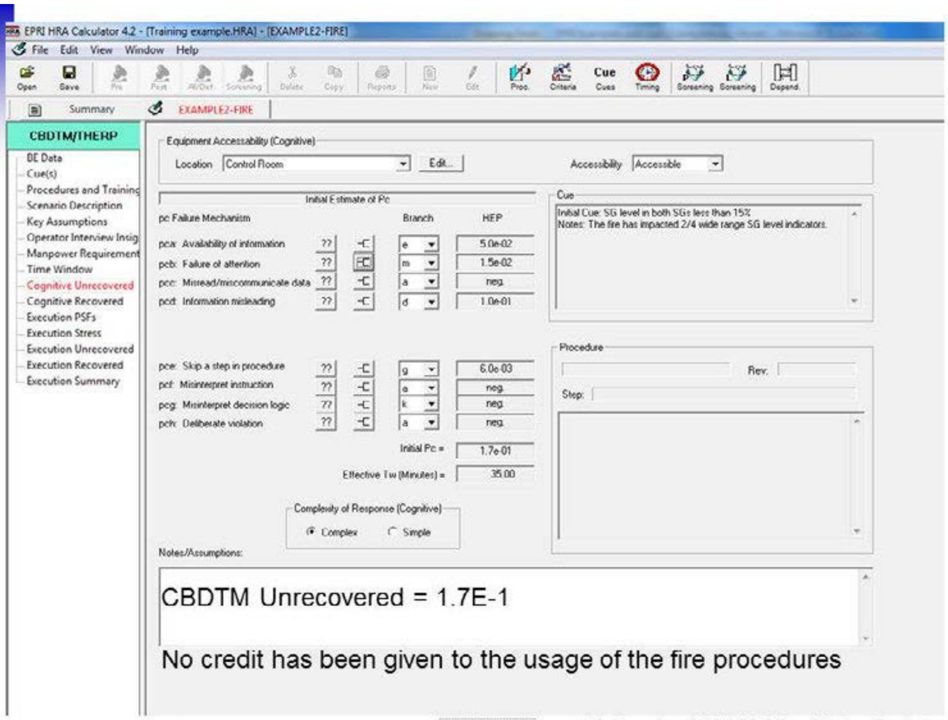
CBDTM decision tree: pc-h Deliberate violation



Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 57

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)



Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 58

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Calculation of Recovery Factor

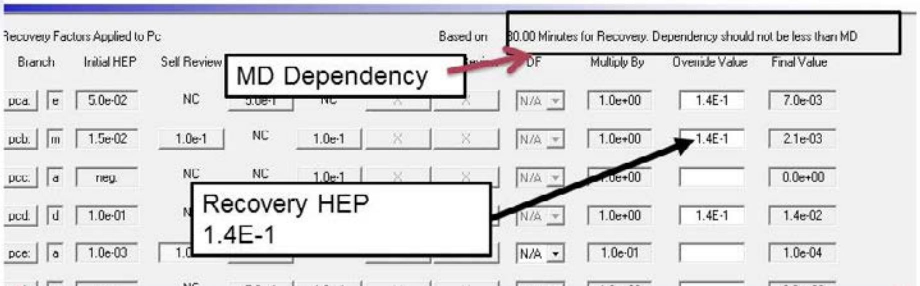
- Using CBDTM an HEP for operators fail to enter fire procedure and diagnose failed indications can be calculated.
- Cue – Fire alarm in the control room. The fire alarm will direct the operators to the fire procedure and correct attachment
- Timeline – This action occurs concurrently with other FR-H.1 actions.
  - T_{sw}= 55 minutes –Longest time in which operators can delay entering FR-H.1 and still successfully perform feed and bleed (60 minutes-5 minutes)
  - T_{delay}= 5 minutes - Time to enter fire procedures
  - T_{cog} = 5 minutes - Time to determine which indications are correct.
  - T_{exe} = 5 minutes - Tm is the time to implement feed and bleed. This time needs to be included to determine the correct time available for recovery.

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 59

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Calculation of Recovery Factor



Recovery HEP is calculated to be 6E-3 and does not include dependencies.

Based on timing a Moderate dependency is assigned.
Recovery HEP with dependency is (1+ 6 X6E-3) / 7 =1.4E-1

P_{cog} with recoveries is 2.3E-2

Fire PRA Workshop 2013 – Charlotte, NC
EPRI Approach Examples

Slide 60

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Execution

- Same execution steps as for Internal Events

Step	Instruction	Omission	Commission	Total	Location
1	Actuate SI	1.3E-3	1.3e-03	1.3e-02	Control Room
2	Verify Adequate RCS Feed Path	1.3E-3	0.0e+00	6.5e-03	Control Room
3	Open 2 PORVS	1.3E-3	1.3e-03	1.3e-02	Control Room
4	Verify Adequate RCS Bleed Path	1.3E-3	0.0e+00	6.5e-03	Control Room

Execution Recovery

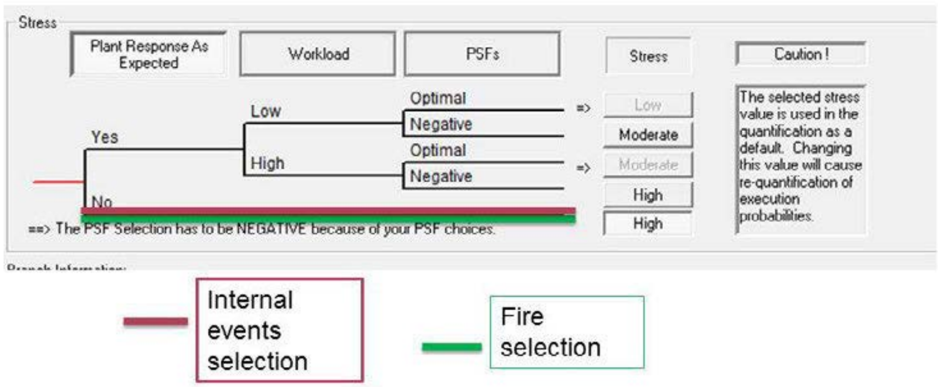
Pexe with Recovery

Crit. Step	Recovery Step	Actions	CD	Prob.	Prob.
1		Actuate SI			1.9e-03
	2	Verify Adequate RCS Feed Path	MD	1.5e-01	
3		Open 2 PORVS			1.9e-03
	4	Verify Adequate RCS Bleed Path	MD	1.5e-01	
				Total Pexe	3.9e-03

Moderate dependency is assigned for recovery

Execution PSFs

- Fire is outside the control room and has no impact on the control room.
- Stress is the same as for internal events



HEP Summary

Operator fails to perform feed and bleed during fire with 2/4 SG levels impacted

Complete Analysis Results

	without Recovery	with Recovery		
Pcog	1.7e-01	2.4e-02	Total HEP	2.8e-02
Pexe	2.6e-02	3.9e-03	Error Factor	5

Operator fails to perform feed and bleed (internal events)

Complete Analysis Results

	without Recovery	with Recovery		
Pcog	1.8e-02	1.1e-03	Total HEP	2.6e-03
Pexe	2.6e-02	1.5e-03	Error Factor	5

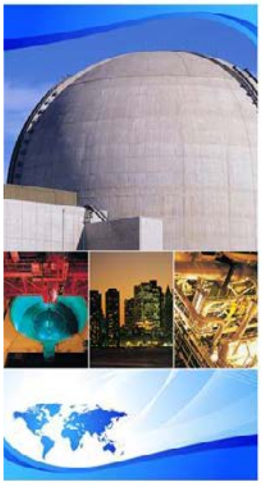
3.10. Detailed Quantification: ATHEANA

ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

CURTISS WRIGHT Flow Control Company SCIENTECH

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE HRA METHODOLOGY:
Task 12 – Fire HRA

DETAILED QUANTIFICATION: ATHEANA

Joint NRC-RES/EPRI Fire PRA Workshop 2012
Bethesda, MD

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of post-fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. Uncertainty analysis

Fire PRA Workshop, 2011, San Diego & Jacksonville
Fire HRA - ATHEANA

Slide 2

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

ATHEANA - Outline

1. Introduction to ATHEANA
2. ASME/ANS PRA Standards Addressed
3. ATHEANA HRA Process
4. ATHEANA guidance for facilitating expert elicitation
5. ATHEANA – What's Going To Be Different For Fire PRA?
6. Addressing Fire-Specific Issues With ATHEANA
7. Fire HRA Exercises Using ATHEANA

Introduction to ATHEANA

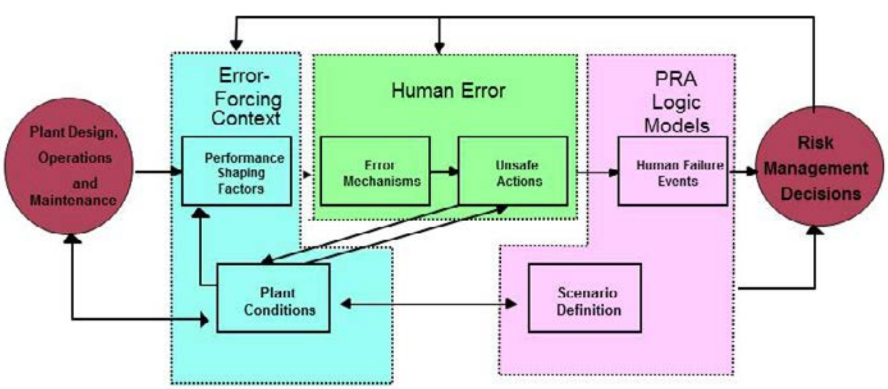
- ATHEANA is…
  - A Technique for Human Event ANAlysis
  - A second-generation HRA method
  - A development of NRC/RES and its contractors
  - An input to NRC's *Good Practices for Implementing Human Reliability Analysis (HRA)*, April 2005
- ATHEANA is documented in:
  - NUREG-1624, Rev. 1, *Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA)*, May 2000.
  - NUREG-1880, *ATHEANA User's Guide*, June 2007.

Introduction to ATHEANA (continued)

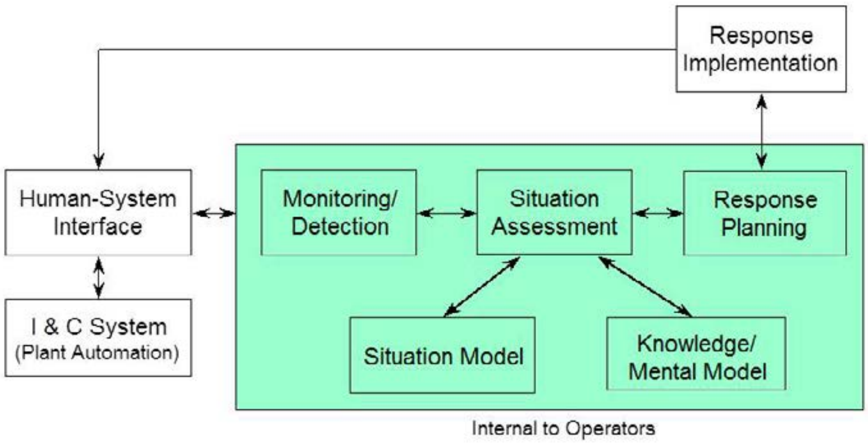
- ATHEANA is…
  - A knowledge-base* for (mostly) at-power, post-initiator HFEs, including:
    - Relevant psychological literature
    - Supporting analyses of historical events
  - A multidisciplinary framework for understanding human error
  - An HRA process (including detailed guidance for performing qualitative analysis)
  - A search scheme for HFEs (including errors of commission)
  - A quantification approach
- Also, ATHEANA provides a basis for performing retrospective analysis of historical events (including example analyses).

But, different knowledge bases* can be used or substituted.

Multidisciplinary framework



Underlying model of operator's behavior



Introduction to ATHEANA (continued)

- The basic premise of ATHEANA:
  - People behave "rationally," even if reason for an action (or inaction) is wrong.
  - Often, when people make errors, they are "set up."
  - People can be "set-up" by **contexts** that can create the *appearance* that the wrong response is correct when, in fact, it is not.
- Analyses of operating experience (particularly events with serious consequences) support this view, e.g.:
  - Nuclear power plant events (e.g., TMI 2, Browns Ferry, Chernobyl)
  - Incidents from a variety of other technologies (e.g., aviation, medicine, chemical processing, maritime)

Introduction to ATHEANA (continued)

Across industries, the following **contextual** factors often have been involved in serious events:

1. The plant behavior is outside the expected range (as represented by procedures, training, and traditional safety analyses).
2. The plant's behavior is not understood.
3. Indications of the actual plant state and behavior are not recognized (sometimes due to instrumentation problems).
4. Prepared plans or procedures are not applicable or helpful for the specific plant conditions.

Introduction to ATHEANA (continued)

Consequently, the principal motivators for developing ATHEANA were:

1. HFEs modeled in most HRA/PRAs are not consistent with the roles played by operators in actual operational experience (including errors of commission and dependencies between actions).
2. The accident record and advances in behavior sciences both support a stronger focus on **context**.
3. Recent advances in psychology ought to be used and integrated with the disciplines of engineering, design, operations and training, human factors, and PRA in modeling HFEs.

Introduction to ATHEANA (continued)

- Overall, the goal of ATHEANA quantification approach is to:
  - Develop an "operational story" (including plant conditions, operational aids such as procedures, and other influencing factors) to explain **why** an operator could failure to perform an action
  - Explain and refine the operational story with plant-specific experts
  - Use the expert judgment of plant-specific personnel (especially operator trainers) to develop failure probabilities for HFEs that require detailed HRA quantification (facilitated by the HRA analyst)

Introduction to ATHEANA (continued)

Key characteristics are:

- Focuses on the **error-forcing context** (i.e., the context that sets up operators), but also addressed the nominal context
- Uses a structured search for problem scenarios (i.e., **error-forcing contexts**) and associated unsafe actions (i.e., operator failures)
- Links plant conditions, performance shaping factors (PSFs) and human error mechanisms through the **context**
- Is experience-based, both in its development and application (e.g., uses knowledge of domain experts such as operators, pilots, trainers)
- Uses multidisciplinary approach and underlying cognitive model of operator behavior
- Explicitly considers operator dependencies (including recovery actions) by developing entire accident sequences
- Uses a facilitator-led, expert elicitation approach for quantification (that allows the plant-specific experience and understanding from operators, operator trainers, and other operations experts to be directly reflected)

Introduction to ATHEANA (continued)

Example ATHEANA applications:

- HRA/PRAs in a prospective analysis of regulatory and industry issues such as pressurized thermal shock (PTS) (3 plants – Oconee, Beaver Valley, Palisades)
- International HRA Empirical Study (Steam Generator Tube Rupture and Loss of Feedwater scenarios)
- DOE's license application for Yucca Mountain waste repository (preclosure facility)
- Qualitative analyses of spent fuel handling (misloads and cask drops) (NUREG/CR-7016 and -7017, February 2012)
- Retrospective event analyses and development of a knowledge-base for fire-specific human performance issues (NUREG/CR – to be published)
- HRA/PRA to evaluate design features of a facility to dismantle chemical weapons

ANS/ASME RA-Sa-2009 Requirements for Fire – At Power High Level Requirements for HEP Quantification

- ATHEANA includes a fully capable detailed HRA quantification approach that satisfies requirements such as:
  - Part 2, HLR-HR-F: Human failure events shall be defined that represent the impact of not properly performing the required responses, in a manner consistent with the structure and level of detail of the accident sequences
  - Part 2, HLR-HR-G: The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self consistent process that addresses the plant-specific and scenario-specific influences on human performances, and addresses potential dependencies between human failure events in the same accident sequence
  - Part 4, HLR-HRA-B: The Fire PRA shall include events where appropriate in the Fire PRA that represent the impacts of incorrect human responses associated with the identified human actions
  - Part 4, HLR-HRA-C: The Fire PRA shall quantify HEPs associated with incorrect responses accounting for the plant-specific and scenario-specific influences on human performance, particularly including the effects of fire
- ...and supporting level requirements such as:
  - Part 2, SRs HR-F1, HR-G3, HR-G7, HR-G8; Part 4 SRs, HRA-B1 [Note 1] and HRA-C1

The ATHEANA HRA process

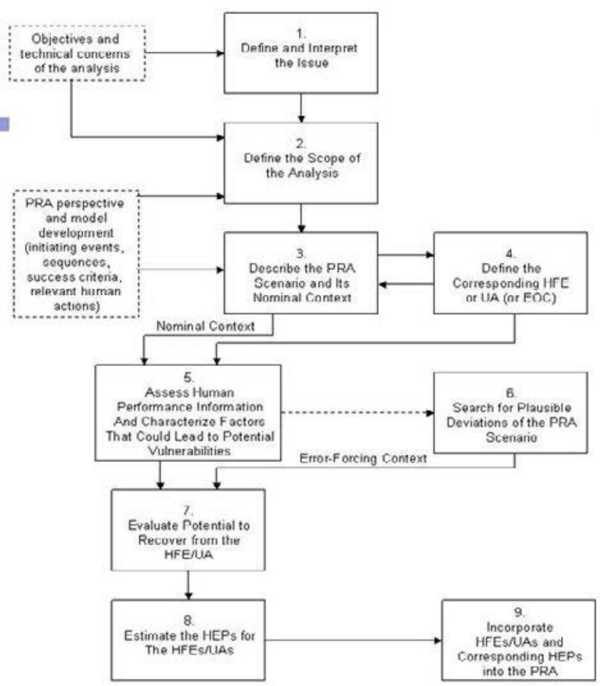
- Step 1: Define and interpret issue of concern
- Step 2: Define scope of analysis
- Step 3: Describe base case scenarios
- Step 4: Define HFEs and unsafe actions (UAs)
- Step 5: Identify potential vulnerabilities
- Step 6: Search for deviations from base case
- Step 7: Evaluate recovery potential
- Step 8: Quantification
- Step 9: Incorporation into PRA

Fire PRA Workshop, 2011, San Diego & Jacksonville
Fire HRA - ATHEANA

Slide 15

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Steps in the ATHEANA Process



Fire PRA Workshop, 2011, San Diego & Jacksonville
Fire HRA - ATHEANA

Slide 16

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

The ATHEANA HRA process

- Not all of these steps are needed for every HRA/PRA job.
- For fire HRA/PRA, certain steps will not need to be performed by ATHEANA, e.g.,
  - NUREG/CR-6850 [EPRI 1011989] and the ANS/ASME PRA Standard already address Steps #1 and #2 (i.e., define and interpret the issue of concern, define the scope of analysis)
  - Deviations from the base case scenario (i.e., Step #6) are **usually** not needed for fire; most fire scenarios are generally challenging enough for operators that we do not have to look for even more unusual conditions
- So, later when we talk about ATHEANA steps, we'll highlight those needed specifically for fire HRA/PRA.

Fire PRA Workshop, 2011, San Diego & Jacksonville
Fire HRA - ATHEANA
Slide 17
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

ATHEANA guidance for facilitating expert elicitation

- ATHEANA uses an expert elicitation approach to develop failure probabilities for HFEs:
  - Described in NUREG-1880, <u>ATHEANA's User's Guide</u>
  - Based on previous expert elicitation approaches, especially:
    - NUREG/CR-6372, Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts" (1997) (a.k.a., NRC's "SSHAC report")
  - ...and consists of:
    - A six-step process, leading to quantification of HFE (and its distribution)
    - Description of who the experts should be
    - General guidance for the facilitator
    - Guidance on addressing uncertainty, controlling for unintentional bias in experts, information to discuss, how to lead discussions and build distributions
    - Guidance on how to educate experts on probabilities and context
    - Guidance on how to build a consensus HEP and its distribution, and perform "sanity checks"

Fire PRA Workshop, 2011, San Diego & Jacksonville
Fire HRA - ATHEANA
Slide 18
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

ATHEANA – What's going to be different for fire PRA?

1. NUREG/CR-6850 [EPRI 1011989] and supporting documents indicate the need for adjustments for a fire-specific knowledge-base (e.g., fire-specific human performance issues).
2. EOCs are limited to those stated in the ASME/ANS PRA Standard.
3. Many *Fire HRA Guidelines* qualitative analysis tasks overlap; may already be performed or started before detailed quantification is performed.
4. The fire **context** may already be sufficiently challenging for operators; ATHEANA steps and activities related to finding an **error-forcing context** may not be needed.

Mapping ATHEANA process steps to Fire HRA Guidelines process

ATHEANA Process Step	Fire HRA Guideline Process Step
Steps 1 & 2: Define issue & scope of analysis	Defined by fire PRA & its scope of analysis – **no additional work needed**
Step 4: Define HFEs and unsafe actions (UAs)	**Covered*** by Chapter 3: Identification and Definition
Steps 3 & 5: Describe PRA scenario & assess human performance information, etc.	Some additional information needed for detailed HRA; but, **mostly covered** by Chapter 4: Qualitative Analysis
Step 6: Search for deviation scenarios	**Probably not needed**; fire scenarios are already "deviations"
Step 7: Assess potential for recovery	Similar to Chapter 6: Recovery
Step 8: Quantification (explicitly addresses dependencies & develops uncertainty distributions)	Different approach than scoping trees (Chapter 5) or CBDT (Appendix C); different approach to dependency & uncertainty (Chapters 7 & 8)

ATHEANA HRA process – highlighting needs for fire HRA

- Step 1: Define and interpret issue of concern
- Step 2: Define scope of analysis
- Step 3: Describe base case scenarios*
- Step 4: Define HFEs and unsafe actions (UAs)*
- Step 5: Identify potential vulnerabilities*
- Step 6: Search for deviations from base case*
- Step 7: Evaluate recovery potential
- Step 8: Quantification
- Step 9: Incorporation into PRA

* Previous fire PRA tasks provide a start on these ATHEANA tasks; for example qualitative analysis is continuous through detailed HRA quantification

Additional ATHEANA needs for fire HRA

1. Some additional qualitative analysis to support Steps 3, 5, (6), 7, and 8, including:
   - Information collection
   - Interviews of operator trainers
2. ATHEANA approach for quantification and recovery
   - With dependency considerations embedded
   - With uncertainty distribution being explicitly developed as part of quantification
3. Adjustments to knowledge-base (per considerations in NUREG/CR-6850 [EPRI 1011989] and others)

Additional ATHEANA needs for fire HRA (continued)

- So, in this presentation, we will only discuss the following steps in the ATHEANA process:
  - Step 3: Describe the base case scenario*
  - Step 5: Identify potential vulnerabilities*
  - Step 6: Search for deviations from base case (often not needed)
  - Step 7: Evaluate recovery potential
  - Step 8: Quantification
- As for the entire process in applying the Fire HRA Guidelines, these steps are **iterative**.

Note: If Step 6 is needed, HFEs may need to be redefined (as in any HRA/PRA, if warranted by plant conditions, timing of plant behavior, etc.). But, Fire HRA Guidelines can address this situation without using Step 2 of ATHEANA explicitly.

Step 3: Describe "base case scenario" (i.e., PRA scenario and its nominal context)

- The base case scenario:
  - represents most realistic description of expected plant and operator behavior for selected issue and initiator
  - provides basis to identify and define deviations from such expectations (found in Step 6)
- Ideally, base case scenario:
  - has a consensus operator model (COM)
  - is well-defined operationally
  - has well-defined physics
  - is well-documented
  - is realistic
- Scenario description often based on FSAR or other well-documented analyses

  In practice, the available information defining a base case is usually less than ideal - analysts must supplement information deficiencies or simply recognize them.

Step 3: Describe "base case scenario" (continued)

- Initial plant conditions
- Sequence of events and expected timing before and following reactor trip
- Plant system and equipment response
- What the operators will see
  - usually trajectories of key plant parameters and indications
- Key operator actions during the scenario progression

NUREG-1921, Section 4 is good resource for this step

Step 3: Examples of information sources

- Plant-specific FSAR (and other design basis documents)
- Safety analyses (e.g., plant-specific, vendor)
- Procedures (e.g., plant-specific EOPs, vendor, basis documents)
- Operator experience (actual and simulator)
- Operator training material and its background documentation
- Plant staff, especially operators, operator trainers, T-H experts
- Plant-specific and industry generic operating experience

Again, NUREG-1921, Section 4 is a good resource

Step 5: Identify potential vulnerabilities

- Identify and characterize factors (e.g., performance shaping factors (PSFs)) that could contribute to crew performance in responding to the various accident scenarios
  - Factors that might increase the likelihood of the HFEs and UAs of interest
  - Helps focus later deviation searches
- Operators and trainers must play a role in this step
  - directly or through question/answer sessions
  - observation of simulator exercises (with relevant scenarios if possible)

Ways to identify potential vulnerabilities

- Investigation of potential vulnerabilities due to biases in operator expectations (training, experience)
  - review training materials, interview trainers, operators
- Understanding of base-case scenario timeline and any inherent difficulties associated with required response
- Identification of operator-action tendencies based on
  - "standardized" responses to indications of plant conditions
  - informal rules
- Evaluation of formal rules and EOPs
  - critical decision points, ambiguities, sources of confusion, timing mismatches, special cases such as "preemptive actions," etc.

Ways to identify potential vulnerabilities (continued)

- Guidance given in NUREG-1921, Section 4, is good starting point
- Additional tools or guidance can be found in ATHEANA documentation, e.g.,
  - NUREG-1624, Revision 1 and NUREG-1880:
    - Summary of operator tendencies (for off-normal plant conditions in PWRs and BWRs), e.g.,
      - steam generator pressure too low or decreasing=> operators decrease steam dump (i.e., cooldown) or isolate tube rupture
    - Examples of informal rules (e.g., believe your indications, protect pumps (i.e., stop if no lube oil pressure))
    - Scenario characteristics that are challenging to operators (e.g., missing information, impasses, tradeoffs, double binds)
    - Parameter characteristics that are challenging (e.g., small change in parameter, slow rate of change in parameter, one or more false indications)

Fire PRA Workshop, 2011, San Diego & Jacksonville
Fire HRA - ATHEANA
Slide 29
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Ways to identify potential vulnerabilities (continued)

- Additional tools and guidance…in ATHEANA… (continued)
  - NUREG-1624:
    - Table 9.18, Examples of information problems (e.g., display failures, human factoring issues)
    - Table 9.19, Physics algorithms in instruments that can confuse operators (e.g., drive versus stem position for valve position indication)
    - Table 9.15b and 9.16b, scenario or parameters characteristics and associated error mechanisms, error types, and potential PSFs
    - Appendix A: Retrospective analyses of six events
    - Appendices B - E: ATHEANA example applications (e.g., SLOCA, loss of service water)
  - NUREG-1880:
    - Table 3.5-1, Relevant time frames for large LOCA and Loss of Main Feedwater (MFW) example scenarios
    - Section 3.5.2.2, Descriptions of PSFs (and associated discussion)
    - Appendix A: Example of an EOP flowchart for loss of MFW scenario

Fire PRA Workshop, 2011, San Diego & Jacksonville
Fire HRA - ATHEANA
Slide 30
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 6: Search for deviations from base case scenario

- Identify deviations from base case likely to result in risk-significant unsafe acts
- Deviations are plant behaviors or conditions that set up unsafe actions by creating mismatches between the proposed plant behavior and:
  - operators' knowledge, expectations, biases and training
  - procedural guidance and timing
- ATHEANA search schemes guide analysts to find real deviations in plant behavior and conditions
  - not just false perceptions in the operators' minds

Step 6: Four search schemes for deviation scenarios

- Identify deviations from the base case scenario using "HAZOP" guide words to discover troublesome ways that the scenario may differ from base case
  - more, less, quicker, slower, repeat ...
- Identify deviations for vulnerabilities associated with procedures and informal rules
  - e.g., changes in timing, sequencing of decision points, etc.
- Identify deviations caused by subtle failures in support systems
  - cause problems for operators to identify what's happening
- Identify deviations that can set up operator tendencies and error types leading towards HFEs/UAs of interest

Step 7: Evaluate potential for recovery

- Possibility of recovering from UAs is considered in this step; similar to recovery analysis when using other detailed HRA quantification methods
- However, for ATHEANA, recovery **always** considers both the complete EFC and the occurrence of other UA(s)
  - in qualitative analysis
  - in quantification (i.e., probability of failed recovery is conditional on probabilities of other operator failures and successes)
- Deviation description is extended to include the scenario characteristics up to the last opportunity for recovery
- Performance of this step linked with quantification - iteration between these steps is likely

Guidance for recovery analysis

- Define the possible recovery action(s) given the initial error corresponding to the HFE/UA has occurred
- Consider the time available to diagnose the need for and perform the recovery action so as to avoid a serious or otherwise undesired condition
- Identify the existence and timing of cues as well as how compelling the cues are that would alert the operators to the need to recover and provide sufficient information to identify the most applicable recovery action(s)
- Identify the existence and timing of additional resources (e.g., additional staff, special tools), if necessary, to perform the recovery

Step 8: Quantification

- Very structured, facilitator led, expert opinion elicitation process
  - leads to consensus distributions of operator failure probabilities
- Considerations in elicitation process (covered in NUREG-1880):
  - Forming the team of experts (include experts familiar with important relevant factors during fire conditions, operator trainers, etc.)
  - Controlling for biases when performing elicitations
  - Addressing uncertainty

ATHEANA quantification: Asks experts two questions

1. Does the operational story make sense?
   - given the specific PRA scenario or sub-scenario
   - given what is known about operators and operations at this plant

2. What is the likelihood that operators will fail as described in the operational story?

Basic formulation for quantification process

- $P\ (HFE|S) = \sum_{ij} P(EFC_i|S) \times P(UA_j|EFC_i, S)$
- HFEs are human failure events modeled in PRA
  - Modeled for a given PRA scenario (S)
  - Can include multiple unsafe actions (UAs) and error-forcing contexts (EFCs)
- First determine probability of the EFC (plant conditions and PSFs) being addressed
- Determine probability of UA given the identified EFC
- If multiple EFCs identified, then quantify a UA given each EFC separately

Six steps to quantification process

1. Discuss HFE and possible influences / contexts using a factor "checklist" as an aid
2. Identify "driving" influencing factors and thus most important contexts to consider
3. Compare these contexts to other familiar contexts and each expert independently provide the initial probability distribution for the HEP considering:
   - "Likely" to fail ~ 0.5 (5 out of 10 would fail)
   - "Infrequently" fails ~ 0.1 (1 out of 10 would fail)
   - "Unlikely" to fail ~ 0.01(1 out of 100 would fail)
   - "Extremely unlikely" to fail ~ 0.001 (1 out of 1000 would fail)

Six steps to quantification process (continued)

4. Each expert discusses and justifies his/her HEP estimate
5. Openly discuss opinions and refine the HFE, associated contexts, and/or HEPs (if needed) – each expert independently provides HEP (may be the same as the initial judgment or may be modified)
6. Arrive at a consensus HEP for use in the PRA

Addressing fire-specific issues with ATHEANA

- ATHEANA should be applied in the same way for fire HRA, as for any other HRA/PRA
- However, the fire-specific operator performance issues should be considered in performing ATHEANA steps (e.g., identifying potential vulnerabilities, quantification)
  - Again, Section 4 provides good basis for issues to address and tools for performing qualitative analysis tasks (e.g., how to collect and interpret timing information, fire-specific issues with respect to use of procedures)
- Plus, some of the information needed to apply ATHEANA may be collected and analyzed already in order to have used either the screening values or scoping approach provided in the Fire HRA Guidelines

Addressing fire-specific issues with ATHEANA (continued)

- Additional guidance/discussion on addressing operator response to spurious indications is provided in NUREG-1921, Appendix C, e.g.,
  - Development of uncertainty ranges in timing estimates (as discussed in Section 4.6.2) can (and have) been developed directly with expert elicitation
  - EOCs due to spurious indications (both recovery, as for scoping approach, and initial failure)
  - Impact of spurious indications as "distractions" (see Section 4.10)

Example qualitative analysis results - Chapter 4

- In applying the Fire HRA Guidelines, the following are examples of information already collected and/or analyzed:
  - Procedures used in fire scenarios
  - Usage of procedures
  - Potential fire effects and their impacts on human performance
  - Fire PRA scenarios with associated equipment and indication failures
  - Possible crew responses to fire scenarios
    - Errors of Commission
    - Errors of Omission

Examples of additional qualitative analysis to support ATHEANA

1. Identify:
   - important decision points or branching, and other possible places in procedures where operators may make different choices
   - plant-specific "informal rules" and other guidance that may supplement or slightly deviate from relevant procedural guidance
   - tradeoffs (e.g., impromptu choices between alternatives) or other difficult decisions that operators may need to make
   - potential situations where operators may not understand the actual plant conditions (e.g., spurious indications)
   - different ways by which an HFE could occur, starting with the fire PRA scenario description, different procedural paths or choices, and the reasons for these different choices

Examples of additional qualitative analysis to support ATHEANA (continued)

2. Develop:
   - insights from training, experience, or demonstration of fire-related operator actions (in- and ex-MCR), including use of specialized equipment
   - timelines or other ways of representing the time sequencing of events in fire scenarios
3. Objective or final result of ATHEANA qualitative analysis:
   - A full operational scenario description, or "operational story," including accident progression and as many "bells and whistles" as are reasonable, such that operator trainers can "put themselves into" scenario
     - Because, in quantification, you will be asking them, "what would your crews do in this situation?"

Examples of additional qualitative analysis to support ATHEANA (continued)

- The resulting operational scenario description may include:
  - Additional plant conditions that will need to be quantified as part of the HFE (unless accident sequence analyst wants to revise event trees or fault trees).
  - Distinctions on timing of plant behavior (that might need to be addressed as part of the HFE, unless logic is revised).
  - Instrument or indication issues (including failures) that will need to be reflected (for fire, might be explicitly part of PRA model, or may not).
  - Different possible procedure paths or response strategies that operators might rationally take.
  - Reasons why operators might take different procedure paths.
  - Credible **recovery actions**.

Likely to need help from operational experts on the last three elements.

Remember…Basic quantification formula?

First, let's simplify; only one EFC for each scenario, S.

So, we have:

$$P(HFE|S) = \sum_j P(UA_j|EFC, S)$$

- S = Full operational story (might not be equivalent to PRA scenario)
- UAs = Different procedure paths leading to undesired outcomes, and associated reasons for taking them
- EFCs = Plant conditions, behavior, PSFs, etc., that are not explicitly modeled in PRA, but needed to represent S

- Probability of each UA is conditional on EFC/S

ATHEANA – Iterating between qualitative analysis and quantification

- Development of operational scenario descriptions should be both for and by operational experts (e.g., trainers).
- Even "during quantification," the analyst should be alert to the need to modify, refine, and/or add details to the operational description of the scenario. For example:
  - During quantification, very different failure probabilities are provided by the expert panel of trainers.
  - When explaining answers, one trainer brings up a possible influence (e.g., a specific plant condition or equipment failure) that no one else has considered.
  - Because everyone agrees to the validity and importance of this factor, the analyst either:
    - Has everyone include this factor in their quantification, or
    - Defines a new HFE to address this newly defined scenario

Fire PRA Workshop, 2011, San Diego & Jacksonville
Fire HRA - ATHEANA

Slide 47

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

ATHEANA – Iterating between qualitative analysis and quantification (continued)

- Based on experience in applying ATHEANA, most of the effort is in identifying and developing the elements of an "operational story" that represents what the experts think is important to operator behavior.
- Once this agreement is reached, reaching a consensus in final quantification by the operational experts is usually not difficult (if using the tools and techniques for facilitating expert elicitation, such as that given in the ATHEANA User's Guide.)

Fire PRA Workshop, 2011, San Diego & Jacksonville
Fire HRA - ATHEANA

Slide 48

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

ATHEANA – Addressing uncertainty in fire HRA/PRA

- Performed as usually would, i.e.,
  - Expert elicitation process for quantification includes:
    - Detailed qualitative discussions to ensure all the available information (evidence) is brought to the table, shared, and agreed upon to the extent possible
    - Detailed identification of the key factors contributing to aleatory and epistemic uncertainty
  - The HEP developed for an HFE in a fire scenario (as for any other scenario) may be made up of combinations of distributions of multiple unsafe actions that have been evaluated separately.
  - Individual distributions combined mathematically into a single distribution.

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

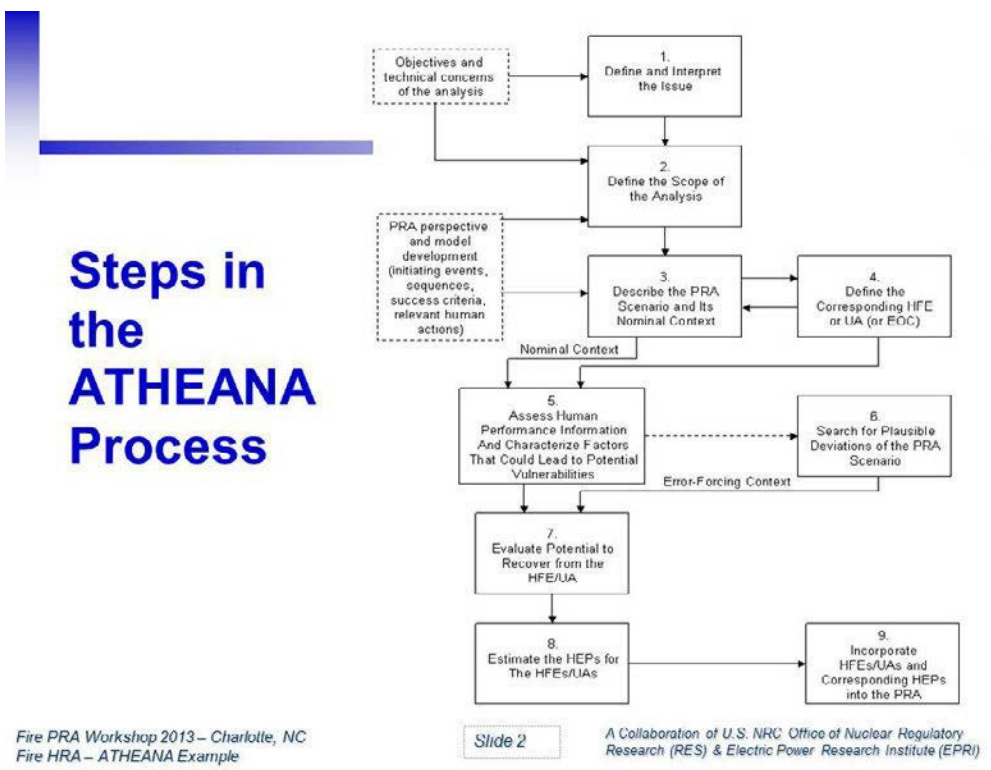
EPRI

CURTISS WRIGHT Flow Control Company
SCIENTECH

Sandia National Laboratories

SAIC® Science Applications International Corporation
From Science to Solutions™

3.11. ATHEANA Example Detailed Fire HFE Quantification



Steps 1&2: Objectives of the Analysis

- Step 1: Define and Interpret the Issue

  Need to identify, model and quantify relevant HFEs for Fire PRA sequences

  Defined by scope of fire PRA.

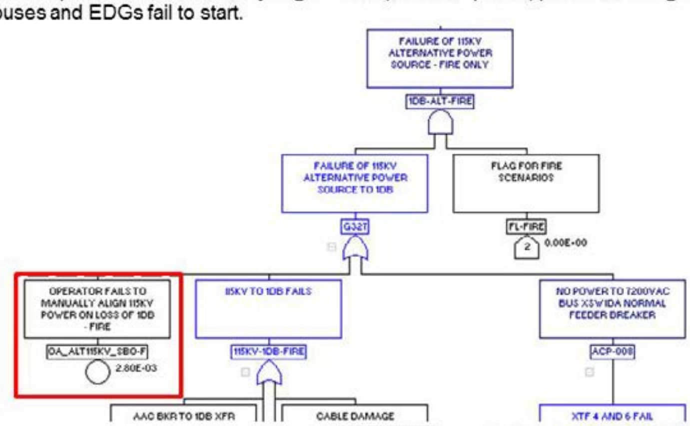
- Step 2: Define the Scope of the Analysis

  Address human actions needed to prevent core damage in fire induced initiating events and subsequent accident sequences under full-power

  Defined by scope of fire PRA.

Step 3: Describe the PRA scenario (nominal context/base case scenario)

- **Initial Conditions**: Single unit two loop PWR with two trains of electrical power. Steady state, full power operation.
  - No out-of-service unavailability pertinent to this scenario
- **Initiating Event**: Fire in turbine room causes SBO
- **HFE:** Operator fails to manually align 115kV (alternate power) power following loss of both buses and EDGs fail to start.



Step 3: Describe the PRA scenario (nominal context/base case scenario)

Accident Sequence

- Fire causes reactor trip
- Reactor trip and Turbine trip successful.
- AFW failed due to the fire.
- PORV spuriously opens due to the fire.
- The Main Generator breaker opens and the BOP buses are powered through XTF0001 (reverse) and XTF0002.
- EDG B starts and the Engineered Safety Feature (ESF) Loading Sequencer loads onto bus.
- EDG B trips due to fire damage. The ESF Loading Sequencer is still sending a signal to trip the normal and alternate feeder breakers (for EDG protection) to the bus.
- All diesels failed – SBO
- DC power remains available until batteries deplete. Batteries will last for 4 hrs

Operators Success Criteria

- Locally trip the alternate feeder breaker by removing power from the ESFLS to remove the trip open signal.
- Energize XSW1DA or 1DB from the alternate power source.

Consequence of failure: Core damage due to stuck open PORV

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 5

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 3: Describe the PRA scenario (nominal context/base case scenario)

- **Procedures**:
  - Upon Reactor Trip, enter EOP-0
    - Step 3 of EOP-0 verifies that buses are energized. Buses are de-energized; this will take the operator to ECA 0.0 [Station Blackout Procedure]
    - Step 10 of ECA 0.0 checks that buses 1DB and 1 DA are energized. Both buses are de-energized; this will take the operator to AOP 304 due to loss of bus with no EDG.
    - Steps 17 and 18 of AOP 304 are the relevant response actions for this HFE:

ACTION/EXPECTED RESPONSE	ALTERNATIVE ACTION
17 **Locally remove power from the Train A ESF Loading Sequencer (XPN-6020 CB-436).** ☐	
18 **Energize XSW1DA from the normal power source:**	18 IF XSW1DA normal power source is NOT available, THEN energize XSW1DA from the alternate power source:
a. Ensure BUS 1DA XFER INIT Switch is in OFF. ☐	a) Ensure BUS 1DA XFER INIT Switch is in OFF. ☐
b. Close BUS 1DA NORM FEED Breaker. ☐	b) Close BUS 1DA ALT FEED Breaker. ☐
c. Verify BUS 1DA potential lights are energized. ☐	c) Verify BUS 1DA potential lights are energized. ☐

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 6

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 3: Describe the PRA scenario (nominal context/base case scenario)

- **Operator action success criteria**: Reset ESFLS to clear trip signal and align alternate power source to XSW1DA.
- **Required Operator Actions:**
  1. Shift Supervisor directs the Control Room Operator to power 1DA
  2. Reset ESFLS to clear trip signal (local action, skill-of-craft)
     a) Local Plant Operator, stationed at or near the MCR, gets ESFLS panel key from the MCR and proceeds to the Relay Room
     b) Dons flash gear
     c) Opens left cabinet (~2ft from floor) and locally removes power from the loading sequencer
     d) Alerts Control Room Operator that the trip signal is clear
  3. Close Breaker in MCR
     a) Control Room Operator will ensure BUS 1DA XFER INIT Switch is in OFF
     b) Close BUS 1DA ALT FEED Breaker
     c) Verify BUS 1DA potential lights are energized

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

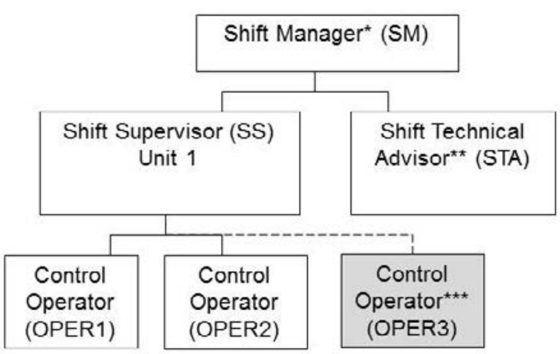
Slide 7

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 3: Describe the PRA scenario (nominal context/base case scenario)

Staffing: Minimum staffing of the plant is as follows:

Inside Control Room:



*Dealing with high-level management issues (e.g., communicating with NRC)
**Normally outside CR. Will be in CR within 10 minutes of reactor trip.
***Daytime only

Outside Control Room:

Local Plant Operator	Crew #
Auxiliary Operators	3
Turbine Hall Operator	2
Aux bldg/Water Treatment	2

Crew composition and titles are plant specific

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 8

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 3: Describe the PRA scenario (nominal context/base case scenario)

- **Interaction with Fire Procedures:**

Time	Event	Comment
T=0min	Fire and Reactor Trip	
T=0min	Control Room dispatches fire brigade to fight the fire; immediate memorized actions (steps 1-3 EOP 0) performed	Fire brigade comprised of 3 Local Plant Operators
T=3min	EOP 0, step 3 indicates SBO. Procedure transition brief held by SS to alert all control room staff that they have an SBO and fire. They will be entering ECA 0.0	OPER1 designated to perform ECA 0.0; OPER2 designated to start reviews of FP
T=5min	OPER1 begins ECA 0.0	
T=7min	Step 4 ECA 0.0 dispatch Local Plant Operator to investigate failure of AFW	Assume this Local Plant Operator will be tied up restoring AFW and not available to assist in additional actions
T=10min	STA arrives	Begins monitoring critical safety functions
T=15min	OPER1 reaches step 10 ECA 0.0, notifies SS that they need to transition to AOP 304	By this time OPER2 has finished reading through FP
T=15min	SS briefs control room staff on the AOP coordination with the FPs	7 contingent time critical action (need in the first hr) in FP; 2 necessary. Confirmed: FP actions will not interfere with AOP actions; sufficient personnel available to do both in parallel. Late actions (>4hr) are postponed until SBO is recovered.
T=20min	OPER1 begins AOP 304; OPER2 begins directing FP actions	OPER2 dispatches 1 Local Plant Operator to perform FP actions
T=35min	OPER1 arrives at step 17 of AOP 304 (locally remove power from ESFLS)	Cue for action

Step 3: Describe the PRA scenario (nominal context/base case scenario)

Staffing Adequacy:

- Analysts walked through the scenario, including the parallel use of the fire procedure and confirmed staffing is adequate to perform this function (see table below).
  - Assessment based on minimum staffing situation (i.e., night time). Daytime shifts would have, at the minimum, an additional Control Room Operator.

Crew Member	Total Available Before Fire	# assisting with fire*	# Available for EOP actions	Required for Bus Alignment
Shift Manager	1	1	0	0
Shift Supervisor	1	Directing both procedures		0
STA	1	0	1	0
Control Room Operators	2	1	1	1
Plant operators	7	4	3	1

*This includes members of fire brigade and staff occupied with FPs or otherwise occupied due to the fire

Step 3: Describe the PRA scenario (nominal context/base case scenario)

Timing analysis:

- Fire ongoing throughout the scenario
  - Detailed fire modeling shows fire will last approximately one hour
- 90 minutes for the total window (from initiator to core damage) based on a thermal hydraulic run for loss of AFW and a station blackout with one primary PORV stuck open
- T_{delay} = 35 min from reactor trip to receiving cue for action (step 17 in AOP 304)
  - Based on Simulator observation for a similar scenario for SBO it took operators 10 minutes to get through ECA 0.0 step 10
    - Simulation based on non-fire SBO, so add an 5 additional minutes to account for the initial coordination
  - Based on operator interviews, estimated additional 20 minutes to reach step 17 of AOP 304
    - Majority of the steps in AOP 304 are checking indicators, so < 1min per step on average
    - Includes 5 minutes to account for AOP/FP meeting to coordinate

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 11

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 3: Describe the PRA scenario (nominal context/base case scenario)

Timing analysis (con't):

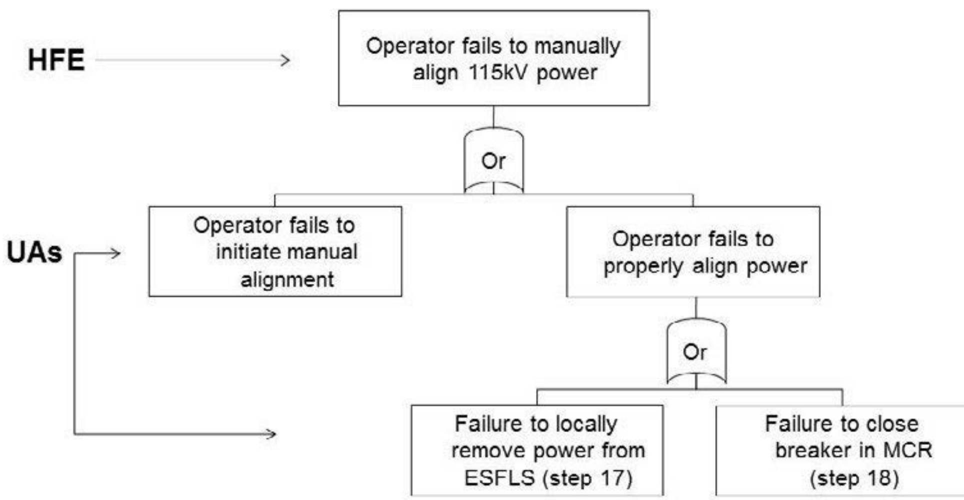
- T_{reqd} = 22 min for diagnosis and execution
  - Diagnosis and SS approval ~2 minutes
  - The action to locally remove power from the Train B ESF Loading Sequencer is trained on using Job Performance Measure (JPM) 12654 – Align ALT Feed Breaker. This JPM has a time requirement to be able to complete the local portion of the actions within 15 minutes, and this has been verified by observations of the JPM. The timing starts once the operator is given the instructions to perform this action and ends once the MCR action had been complete (end of step 18).
    - As part of this JPM the operators train on putting on flash gear which is required to locally remove power from the Train B ESF Loading Sequencer. The flash gear is stored in a cabinet at the entrance to the relay room.
  - After the operators complete the local action they will need to return to the control room to tell the control room operators they were successful. This additional travel time is expected to take 5 minutes.
    - Under ideal conditions the Local Plant Operator could use the phone to call the control room. However, for fire, no cable tracing was performed on the phone lines so the telephones are assumed to unavailable. Radio unavailable during SBO.

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 12

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 4: Define HFE and Unsafe Actions



Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 13

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 4: Define HFE and Unsafe Actions

- **HFE**:
  - Operator fails to manually align 115kV power (alternate power source) given an SBO.
  - HFE defined as part of previous steps of Fire HRA process (Identification and Definition) but unsafe actions must be defined here if applicable.
- **Cues**:
  - Multiple Indications of Loss of Buses1DA and 1DB with EDG not Available. SS makes call to power 1DA after buses have been inspected.
  - AOP-304, Step 17: Locally remove from the Train A ESFLS (Local, Skill-of-Craft action).
  - AOP-304, Step 18: Energize XSW1DA from the normal power source (MCR, proceduralized action):
    - Ensure BUS 1DA XFER INIT Switch is in OFF
    - Close BUS 1DA ALT FEED Breaker
    - Verify BUS 1DA potential lights are energized

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 14

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 4: Define HFE and Unsafe Actions

- Unsafe Actions:
  - Control room crew actions:
    1. Fails to initiate manual alignment (EOO)
    2. Fails to close breaker in MCR (to properly align alternate power) (EOC)
       a) Fails to recover from EOC (long time window, immediate feedback)
  - Local operator actions:
    3. Fails to locally remove power Train A ESFLS (only credible failure mode is EOC)
       a) Fails to recover from EOC (with no local feedback available)

Potential Failure Modes and Recovery

- **Unsafe actions:**
  1. Control room crew fails to initiate manual alignment (EOO):

     Given the nature of the action and the training, it is unlikely that the crew will skip either step 17 or step 18, but it is possible that sufficient distractions (and other factors elongating the timeline) exist that the crew could **fail to complete the action in time**

  2. Control room crew fails to close breaker in MCR (to properly align alternate power) (EOC)

     This unsafe action is not considered further because there is a very high potential for recovery, e.g.,

     –Good cues for recovery

     –Long Time Frame (35 minute time available for recovery)

     –Fire extinguished by this point in time

Potential Failure Modes and Recovery (cont.)

- Unsafe actions (continued):
  3. Local operator fails to locally remove power Train A ESFLS (only credible failure mode is EOC), **AND**

  3a. Local operator fails to recover from EOC (with no local feedback available)

  EOC:
  - Well proceduralized/skill-of-craft step with good training
  - EOC failure modes may include: Open wrong switch (fail local action)
  - Diagnosis is largely performed by CR operators; plant operators must simply execute the required actions and report back to CR (for purposes of coordination)

  Recovery of EOC: In this case, there is no feedback available to the local operator that the wrong action was performed. Clear indications in the MCR that the ESFLS signal has not been cleared; the local operator will not get this feedback until he returns to the MCR to report back. After being notified that the wrong action has been performed, the local operator must return to the location of the ESFLS switch.

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 17

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Steps 5-8: Understanding the Context (Iterative Process)

Step 5: Identify Potential Vulnerabilities

Step 6: Search for Plausible Scenario Variations

Step 7: Evaluate Potential to Recover

Step 8a: Create Operational Story/Stories

Step 8b: Numerical Assessment

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 18

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Group Exercise

- **Break into groups and identify factor that could:**
  - Create potential vulnerabilities in the crew's ability to respond to the scenario(s) of interest and increase the likelihood of the HFEs or UAs
  - Failure modes (i.e., how can the scenario go wrong?)
  - Lead to variability in crew response

- **You may want to consider the following**
  - Division of Labor/Workload
  - Procedures
  - Training
  - Complexity
  - Environment
  - Special Requirements (e.g., keys)
  - Stress due to Fire
  - Communication
  - Crew Coordination
  - Variations in Timing
  - Variation in Crew Characteristics

Group Exercise (2)

- Which factors are drivers? [Error Forcing Contexts]
  - Note: Normally this would be done with the input of those knowledgeable of the plant and crews (e.g., operators, trainers) and any assumptions would be verified against the plant's operations

Potential Vulnerabilities

- **Training**: Operators trained on procedures, including applicable alternative actions. Non-fire SBO scenarios are common in training and "Align ALT Feed Breaker" is a Job Performance Measure which is trained on bi-annually. Annual training on Fire Procedures. *Trained as crew on SBO, not single operator. Fire Procedure training may not include doing the procedures in parallel.*
- **Parallel Procedures**: The fire is ongoing during this scenario, so a portion of the staff will be unavailable to help with the EOPs as they will be in the fire procedures. Through operator talk-throughs verified that adequate personnel are available for the necessary actions in this scenario. While operators will be going through two procedures in parallel (FP and EOP), the relevant steps of the FP have been examined and do not conflict with the EOP actions. While the Control Room Operators will be operating in parallel, the Shift Supervisor's attention will be split and he is a key decision point at several places in the procedure.
- **Complexity:** Local action to remove power from ESFLS is a simple, skill-of-craft action.
- **Environment:**
  - **Availability and Accessibility:** Given location of fire and layout of plant, the relay room is accessible and there is no degraded environment (e.g., no smoke) in the relay room or en route to the relay room.
  - **Visibility:** Given a SBO event, lighting will be significantly reduced (i.e., flashlights and/or emergency lighting). Training discusses hese conditions.
  - **Heat/Humidity**: Normal – fire effects do not reach this area, however, after some time (>action window) there could be a rise in temperature due to SBO.

Potential Vulnerabilities

- **Stress due to Fire:** Some stress due to on-going fire and related distractions.
- **Communications:** Communication lines impacted by SBO (no radios) and landlines potentially impacted by fire (no cable tracing). Timeline adjusted appropriately.
  - Previous steps in the ECA/AOP (e.g., local actions such as step 13) might cause delays due to extra time required for communication, delaying the cue (step 17).
  - Generally, local plant operators have to travel back to MCR to report
- **Efficiency of crew coordination:**
  - Crew variations that could result in variability in the time to perform actions and effectiveness of communication back to control room.
  - Too much focus on fire.
  - "Weaker" crews.
- **Special Requirements:**
  - Operators will need key to access relay room; all doors locked on loss of power.
  - Change in security configuration due to SBO may require operators to take a different pathway or some doors which would otherwise be open may now be closed and locked. Not all operators have all keys.

Step 8: Quantification (6 Steps Overview)

1: Discuss HFE and possible influences / contexts using a factor "checklist" as an aid

2: Identify "driving" influencing factors and thus most important contexts to consider (e.g., operational story)

3: Compare these contexts to other familiar contexts and each expert independently provide the initial probability distribution for the HEP based on a common calibration scale.

4: Each expert discuss and justify their HEP

5: Openly discuss opinions and refine the HFE, associated contexts, and/or HEPs (if needed) – each expert independently provides HEP (may be the same as the initial judgment or may be modified)

6: Arrive at a consensus HEP for use in the PRA

Step 8: Quantification (Operational Story)

- Not limited to one operational story, particularly if the analysts have identified multiple credible contexts [EFCs] that need to be examined separately.
- A full operational scenario description, or "operational story," including accident progression and as many "bells and whistles" as are reasonable, such that operator trainers can "put themselves into" scenario.
  - In quantification, you will be asking them, "what would your crews do in this situation?"
- The resulting operational scenario description may include:
  - Additional plant conditions that will need to be quantified as part of the HFE (unless accident sequence analyst wants to revise event trees or fault trees).
  - Distinctions on timing of plant behavior (that might need to be addressed as part of the HFE, unless logic is revised).
  - Instrument or indication issues (including failures) that will need to be reflected (for fire, might be explicitly part of PRA model, or may not).
  - Different possible procedure paths or response strategies that operators might rationally take.
  - Reasons why operators might take different procedure paths.
  - Credible **recovery actions**.

Step 8: Quantification (Operational Story, UA1) Operator Fails to Initiate Manual Alignment

Possible factors/sub-scenario to explore with experts in:

- Staffing variations: can be two sub-cases if large impact on crew performance
  - Night time, minimal staffing (2 Control Room Operators)
  - Day time, normal staffing (3 Control Room Operators)
- Crew variations, such as these two extremes in possible timing outcomes:
  - Methodical crew that is good at taking time to work through the procedures and talk through potential conflicts. The crew works well as a team and rely on each other a lot. Training is done as a team on both the non-fire SBO procedures and the fire procedure, so the Control Room Operators are a bit slower in working through their respective procedures when they are done in parallel, depending heavily on the Shift Supervisor for coordination, OR
  - Aggressive crew, good at planning ahead, working fairly autonomously but coordinating when needed. Efficient at parallel procedures.
- Weak team members, i.e., OPER1 is struggling to keep pace with the rest of the team. There may or may not be an OPER3 that is available to look at boards and help with EOPs and/or FPs.

Step 8: Quantification (Operational Story, UA1) Operator Fails to Initiate Manual Alignment

Possible factors/sub-scenario to explore with experts:

- Variations in SS experience, command & control style, & so forth, e.g.,
  - SS's first actual fire and, because it is a fairly big fire, he gets very focused on fire and becomes less cognizant of timeline or becomes a bottle neck for key decisions.
  - SS calm under stress and has no problem coordinating the two procedures. Team is working at a fairly fast pace and multi-tasking well (e.g., dealing with distractions), but working at the top of their capacity.
- Timing Variations:
  - Delays in previous steps due to combination of radio unavailability and operators having to "hunt down" appropriate keys due to change in security configuration for SBO.
- Other:
  - Fairly significant fire (lasts 60 min), so there are many distractions (e.g., failed indicators and/or spurious indicators not directly relevant to this HFE, but may take time/attention away from operators)
  - End of shift fatigue
- **Overall, explore what factors (e.g., "slow crew" and other delays), result in crew missing timeframe to take action.**

Step 8: Quantification (Operational Story, UA3/3a) Fail Local Action

Possible factors/sub-scenario to explore with experts:

Unsafe action #3 (EOC):

- Training of non-fire SBO only; JPM timing based on average crew time, but accounts for many Local Plant Operators to be available to help with the procedure. With only two Local Plant Operators available for the EOP/AOP, the operator in question may be fatigued from rushing around and performing the higher workload.
- Timing Variations:
  - Delays in previous steps due to combination of radio unavailability and operators having to "hunt down" appropriate keys due to change in security configuration for SBO.
- Given fast pace and general stress, the Local Plant Operator may feel rushed and open the wrong switch

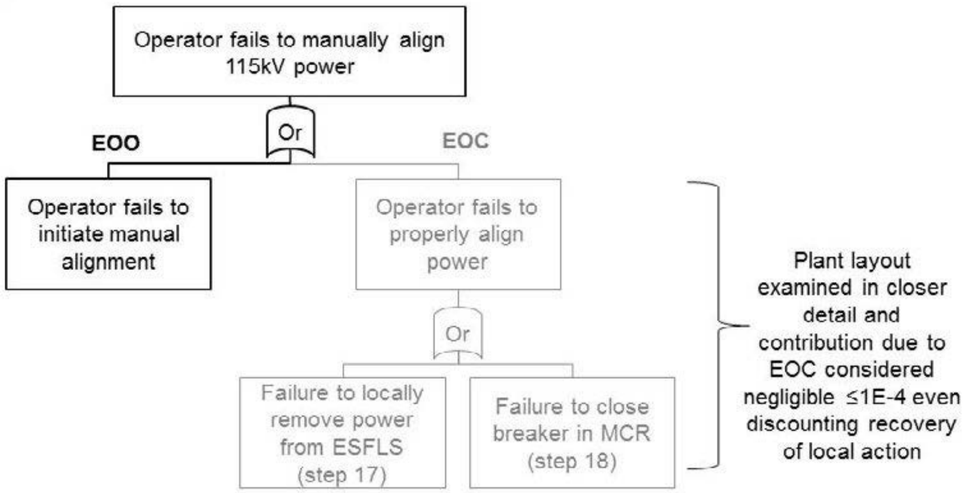
Step 8: Quantification (Operational Story, UA3/3a) Fail Local Action

Possible factors/sub-scenario to explore with experts:

Unsafe action #3a (Failure to recover EOC):

- Staffing:
  - Variations in staffing not applicable to this failure mode (i.e., 2 or 3 CROs)
  - 2 Local Plant Operators available for assistance with this action
- Recovery includes:
  - Diagnosis of problem (good cues); 5-10 minutes
    - Clear indications in the MCR that the ESFLS signal has not been cleared.
  - Action time (including travel time)
    - 20-25 minutes because, while OPER1 knows right away that the ESFLS switch has not been cleared, he has to wait until the Local Plant Operator gets back to re-dispatch him to perform the local action. Need to account for travel time and time to perform the local <u>and</u> MCR actions.
- Fire is extinguished at this point.
- Adequate time for recovery
  - 25-35 minutes required compared to the nominal 55 minutes available.

Logic of Failure Modes



Quantifying Unsafe Action #1 (EOO)

- Driving factors:
  - Slow crew
  - Excessive travel time for local actions extends timeline
  - Mismatch between training (heavy interaction as crew) and reality (relatively autonomous, especially with minimum staffing)
  - Distractions and stress due to fire
  - SS is a funnel point for decisions
- Staffing identified as a driver, so can split this scenario into 2 contexts:
  - 2 Control Room Operators available (Minimal Staffing): 33%
  - 3 Control Room Operators available (Normal Staffing): 67%
- Given "slow and careful" crew, they are unlikely to make a mistake in the action, but may come close to missing the action time window (see next slide).
- "Nominal" case accounted for by shape of the distributions
  - If heavily weighted to left, positive or nominal factors more likely; having the right combination of "driving" factors is less likely

Timing Variations

- Timing is a driving factor in the Operational Story
  - Would ask "experts" to develop a more detailed analysis of potential variations in timing (e.g., more explanations, more developed description of possible scenario variations, detailed histogram of probability of timing for both arrival at Step 17 and performance of required actions)
  - Might separate HFE into two or more separate HFEs to address different timing for different scenarios
- Variations in timing due to factors discussed earlier:
  - Could there be variations in the scenario (e.g., additional minor distractions in working through procedure?
    - "Experts" estimate minor variations: **10-15 additional minutes** to get to critical procedure step
  - Could there be variations in the time to perform (especially with different crews, availability of equipment, communication)?
    - "Experts" estimate minor variations: **5-10 additional minutes** to perform critical procedure steps
- Overall, could reduce time for recovery to as little as **8 minutes**. This, however, does not jeopardize the timeline for the actions themselves.

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 31

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 8: Quantification (Numerical Assessment)

- Combining Multiple Contexts

$$P(HFE|S) = \sum_{j}\sum_{i(j)} P(EFC_i|S) * P(UA_j|EFC_i,S)$$

- Only one dominant UA, so this formula simplifies to:

$$P(HFE|S) = \sum_{i} P(UA|EFC_i,S)$$

- Two distributions need to be estimated
  - Minimal Staffing
  - Normal Staffing

- Only one distribution will be estimated here for illustration

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 32

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Step 8: Quantification (Calibrate Experts)

Circumstance	Probability	Meaning
Operator(s) is "Certain" to fail	1.0	Failure is ensured. All crews/operators would not perform the desired action correctly and on time.
Operator(s) is "Likely" to fail	~0.5	5 out of 10 operators would fail. The level of difficulty is sufficiently high that we should see many failures if all the crews/operators were to experience this scenario.
Operator(s) would "Infrequently" fail	~0.1	1 out of 10 would fail. The level of difficulty is moderately high, such that we should see an occasional failure if all of the crew/operators were to experience this scenario.
Operator(s) is "Unlikely" to fail	~0.01	1 out of 100 would fail. The level of difficulty is quite low and we should not see any failures if all the crews/operators were to experience this scenario.
Operator(s) is "Extremely Unlikely" to fail	~0.001	1 out of 1000 would fail. This desired action is so easy that it is almost inconceivable that any crew/operator would fail to perform the desired action correctly and on time.

Note: These values are meant as calibration points, not discrete values. The 1E-03 values is not meant to be a lower bound.

Step 8: Quantification (Numerical Assessment)

- Very structured, facilitator led, expert opinion elicitation process
  - leads to consensus distributions of operator failure probabilities
- Considerations in elicitation process (covered in NUREG-1880):
  - Forming the team of experts (include experts familiar with important relevant factors during fire conditions, operator trainers, etc.)
  - Controlling for biases when performing elicitations
  - Addressing uncertainty
- Distribution characteristics:
  - the 99th percentile is the HEP for the worst coincident (but not too unlikely) set of negative influences representing a very strong EFC
  - the 1st percentile is the HEP for the best coincident set of positive influences representing a weak EFC (actually a very positive context
  - dependency considerations embedded
  - uncertainty distribution explicitly considered
- **For this illustrative example an HRA SME was used to derive the HEP; this would not normally be sufficient for an actual quantification.**

Step 8: Quantification

- A tip for expert elicitation facilitators:
  - In order to get "experts" to better access their knowledge (i.e., not just remember recent history), you can use examples from real events (i.e., "stories") to illustrate how operators can do "surprising" things (but for good reasons.
    - You know that you've succeeded in getting access to this deeper knowledge when the "experts" start exchanging stories (e.g., "do you remember when 'Charlie' ….?" "I can remember a time or two kind of like that….")

Step 8: Quantification (Bases for Consensus Distribution)

	Percentiles						
Analyst	1st	10th	25th	50th	75th	90th	99th
Larry	0.00001	0.0001	0.0007	0.001	0.005	0.007	0.01
Moe	0.0001	0.0003	0.001	0.005	0.007	0.03	0.07
Curly	0.00001	0.00005	0.0007	0.003	0.005	0.01	0.05
Consensus	**1E-04**	**3E-04**	**1E-03**	**3E-03**	**5E-03**	**1E-02**	**5E-02**

- **Bases for Consensus Distribution:**
  - Under normal circumstances, the action is "Extremely Unlikely" to fail, but the shortened time frame due to no radio communication in combination with potential coordination complications from the fire may produce some difficulties for the crews.
    - Holistically, on average the action was determined to be "Extremely Unlikely" because actions are well trained, proceduralized/skill-of-craft, long timeline, a high potential for recovery and cues are clear so little potential for confusion or mis-direction.
    - Probability capped at 1E-04
    - Worst case falls between "Unlikely" to fail and "Infrequently" fails because even in the worst case they still have buffer time.
    - Tails: effectiveness of crew collaboration, specifics of timing

Step 9: Incorporating HEP into PRA

- When quantifying a scenario with multiple contexts, need to combine weighted distributions. Discrete distributions can be combined using a convolution:

$$(f * g)[n] = \sum_{m=0}^{t} f[n-m]\, g[m]$$

  - Recommend using a statistical software package (e.g., Crystal Ball)

- Depending on the PRA needs, you may:
  - Provide the entire consensus histogram as your answer.
  - Need to develop a mean value for the distribution using a software tool (e.g., Crystal Ball).

- NUREG-1880 provides some guidance and cautions on the development of mean values.

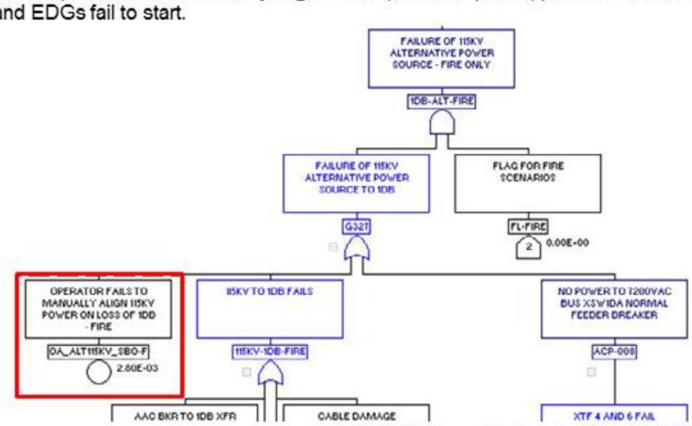
What if…

- What if communication was not impacted, how would the analysis change?
- What if there were not clearly enough people to complete the actions, how would the analysis change?
- What if the operators had to take a detour that comes close to the fire?

SCOPING ANALYSIS OF FIRE + SBO

Review of HFE

- **Initial Conditions**: Single unit two loop PWR with two trains of electrical power. Steady state, full power operation. Night shift with minimal staff onsite.
  - No out-of-service unavailability pertinent to this scenario
- **Initiating Event**: Fire in turbine room causes SBO
- **HFE:** Operator fails to manually align 115kV (alternate power) power on loss of both buses and EDGs fail to start.



Minimum Criteria

1. Procedures
   - Plant procedures covering each operator action being modeled
   - Support both diagnosis & execution of the action

   Local action (step 17) is skill-of-craft; MCR action (step 18) well proceduralized.

2. Training – on the procedures and the actions

   Regular training on non-fire SBO, including alternative actions. Training on FPs.

3. Availability and Accessibility of Equipment
   - Key to ESFLS Panel needed, but available in MCR

   Key to ESFLS Panel needed, but available in MCR. Flash gear needed, but available locally.

Feasibility

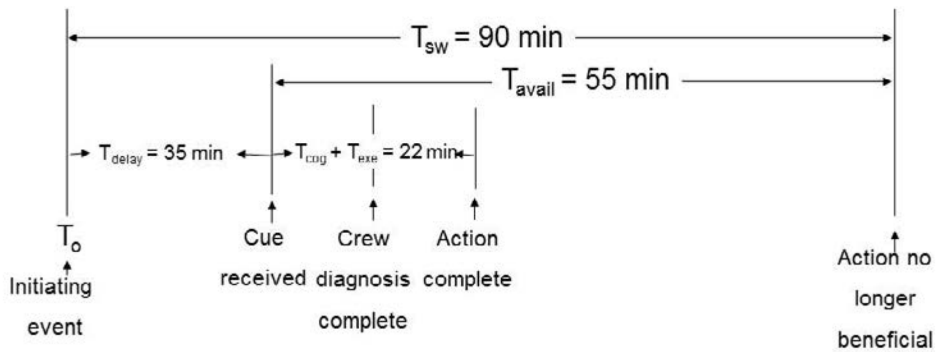
•**Timing analysis**:

- T_{sw}: Assume 90 minutes for the total window (IE to core damage) based on a thermal hydraulic run for loss of AFW and a station blackout with one primary PORV stuck open.
- T_{delay} = 35 min from reactor trip to receiving cue for action (step 17 AOP 304)
- $T_{cog} + T_{exe}$ = 22 min for diagnosis and execution

•**Feasible?** Yes time available (90 minutes) is greater than time for action (55 minutes).

Time Margin

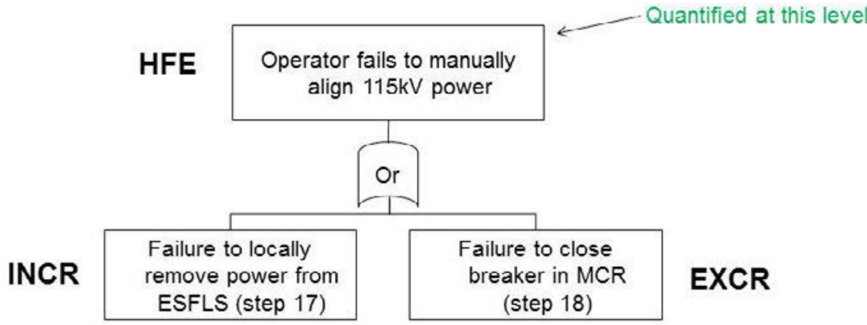
$$\text{Time Margin} = \frac{T_{avail} - (T_{cog} + T_{exe})}{(T_{cog} + T_{exe})} * 100\% = \frac{55 - 22}{22} * 100\% = 150\%$$



Assessing Key Conditions & PSFs within the Scoping Flowcharts

- How well the procedures match the scenario
- Response execution complexity
- Timing of cues for the action relative to expected fire suppression time
- Action time window
  - Short time window = 30 minutes or less
  - Long time window = greater than 30 minutes
- Level of smoke and other hazardous elements in the action areas
  - Need for special equipment (e.g., SCBA)
  - Impairment of vision or prevention of the execution of the action
- Accessibility

HFE Breakdown



While the HFE can be broken down into multiple steps (INCR and EXCR), because this is defined as one HFE (based on the fact it is one diagnostic step), we will quantify this HFE using the EXCR tree because it is more conservative.

Fire PRA Workshop 2013 – Charlotte, NC
Fire HRA – ATHEANA Example

Slide 45

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Search Scheme

Scoping Analysis:

•**Define HFE:** Failure to locally remove power from ESFLS (step 17). This includes both the diagnosis and the execution.

•**Does it meet the minimum criteria**? Yes

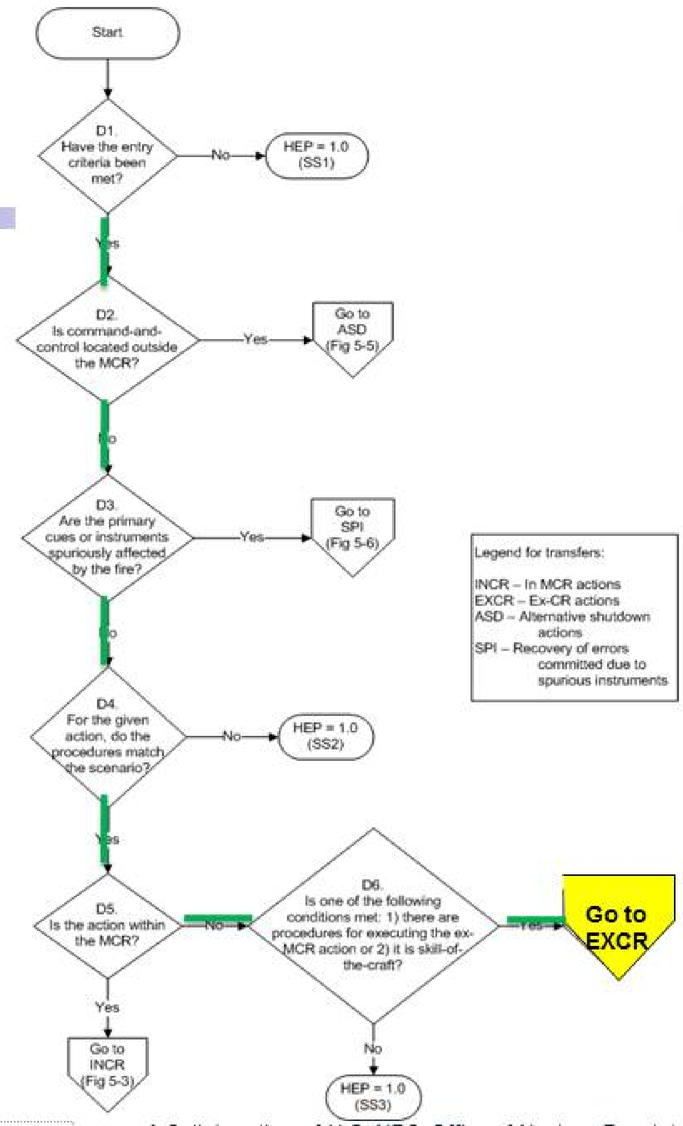
1)Procedures are available
2)Training is performed on the procedure
3)The key to the Relay Room is determined to be accessible

•**Is the action Feasible?** Yes

1)Demonstrated sufficient time to perform action

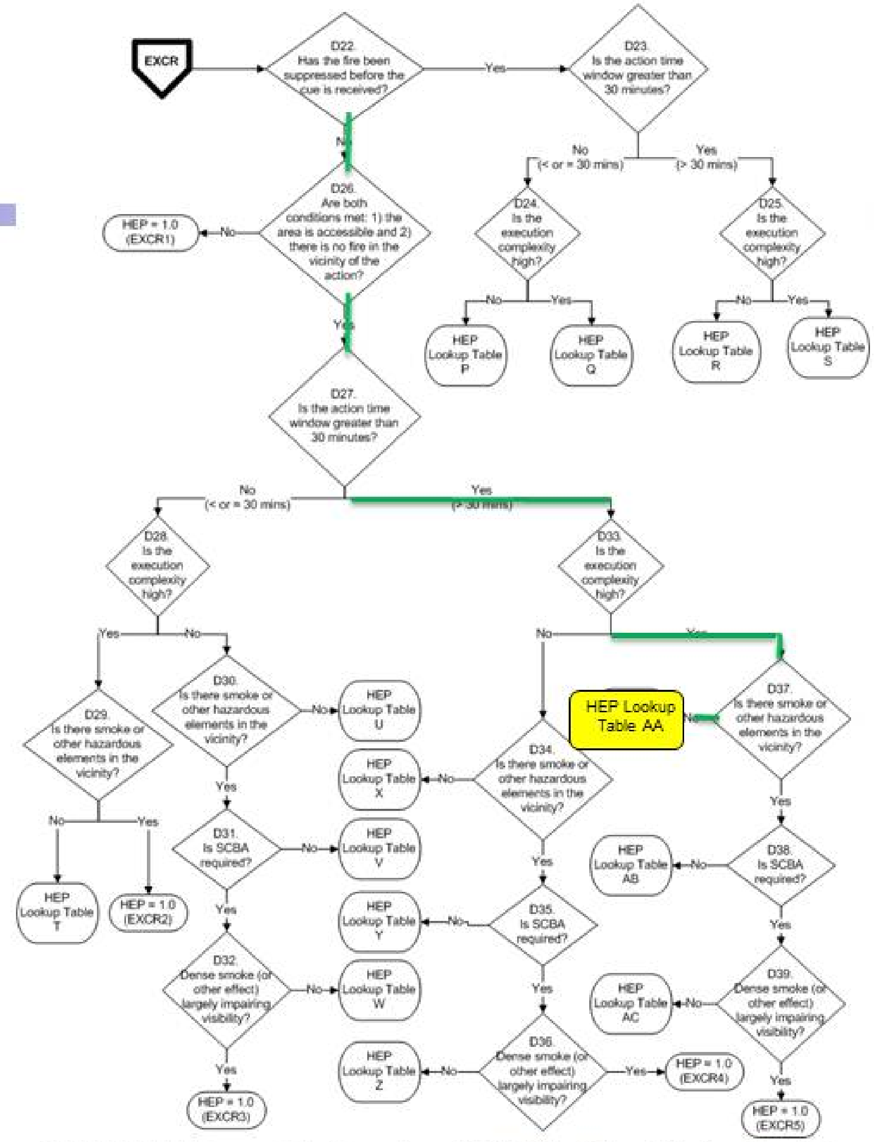
•**Selection Scheme**:

1)D1: Entry criteria are met
2)D2: command and control in MCR
3)D3: primary cues/instrument not spuriously affected by fire
4)D4: procedures match the scenario
5)D5: some actions within MCR, but key actions outside MCR, so use EXCR tree
6)D6: procedures available/skill-of-craft
7)GO TO EXCR TREE



HFE

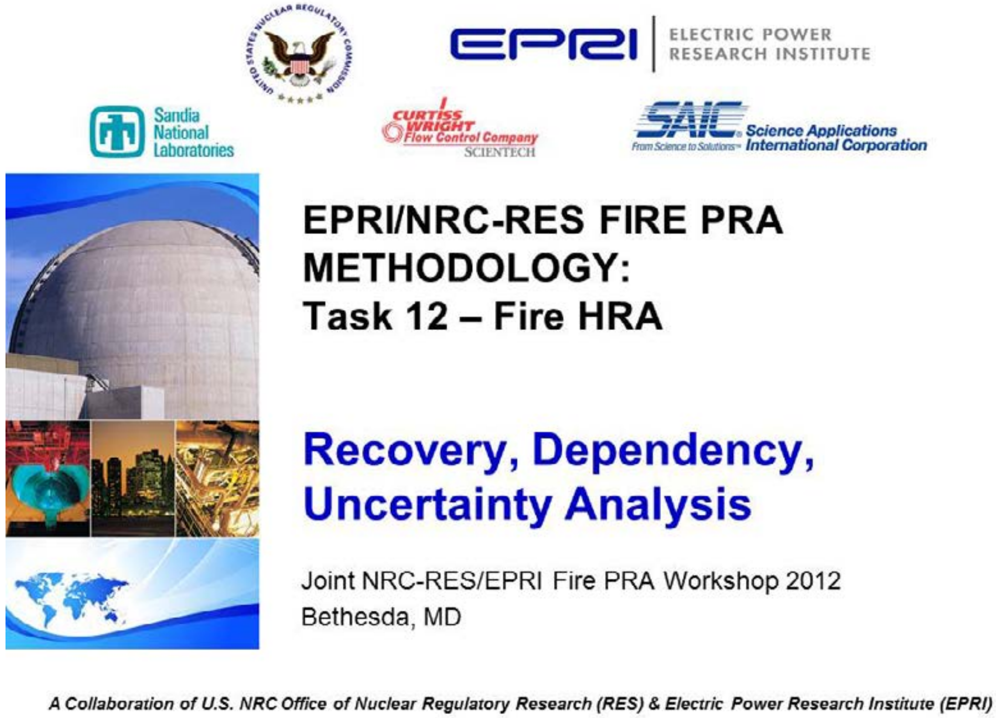
- Local Action
  - D22: Fire is ongoing
  - D26: Area accessible and no fire in vicinity.
  - D27: Time window is greater than 30 min (90 – 35 = 55min).
  - D33: High complexity in execution due to multiple step/locations
  - D37: No smoke.
  - Time Margin >100%
  - **Look up Table AA value = EXCR36 = 0.1.**

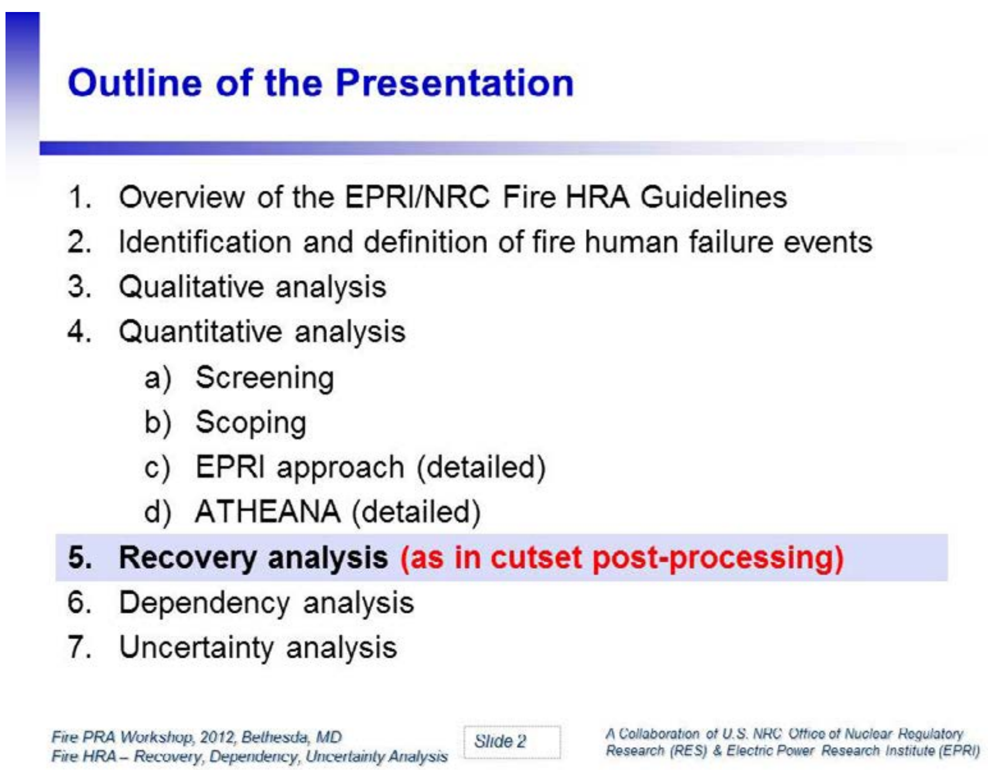


Slide 47

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

3.12. Recovery, Dependency, Uncertainty Analysis





Applicable HLRs (per the PRA Standard)
Recovery

- HLR-AS-A: The accident sequence analysis shall describe the plant-specific scenarios that can lead to core damage following each modeled initiating event. These scenarios shall address system responses and operator actions, including recovery actions that support the key safety functions necessary to prevent core damage (11 SRs)
- HLR-HR-H: Recovery actions (at the cutset or scenario level) shall be modeled only if it has been demonstrated that the action is plausible and feasible for those scenarios to which they are applied. Estimates of probabilities of failure shall address dependency on prior human failures in the scenario (3 SRs)
- HLR-QU-A: The level 1 quantification shall quantify core damage frequency and shall support the quantification of LERF (5 SRs, 1 specific to recovery)
- HLR-HRA-D: The Fire PRA shall include recovery actions only if it has been demonstrated that the action is plausible and feasible for those scenarios to which it applies, particularly accounting for the effects of fires (2 SRs)

Recovery per NFPA 805

- Recovery actions as defined under NFPA 805 are what used to be generally referred to in the fire protection community as "operator manual actions" (or OMAs).
- In this context, recovery refers only to actions performed outside of a primary control station (PCS). Note that the MCR is not the only PCS.
- Under NFPA 805, total transfer of control from the MCR to a dedicated or alternate shutdown location means there is a new PCS, and operations conducted there are not recovery actions (and neither are the actions required to transfer control).
- All actions away from a primary control station are considered recovery actions under NFPA 805, whether or not they are considered recovery actions in the PRA, and plant licensees must evaluate the additional risk of their use according to NFPA 805.
- **THIS IS NOT THE DEFINITION OF RECOVERY USED IN THE FIRE HRA GUIDELINES**

Recovery types

There are three types of recovery actions of concern for fire HRAs. These are:

- Type 1 – Recovery within the same HFE, which is treated in the evaluation of the basic HEP
- Type 2 - Standard PRA concept of recovering cutsets by adding a new human action to the sequence

  (focus of this course segment)
- Type 3 - Modeling the fire brigade and their actions to extinguish the fire. According to NUREG/CR-6850 (EPRI 1011989), this type of recovery action is treated in the fire modeling task via statistical models derived from fire suppression event data (as updated via FAQ 08-0050)

Recovery within the same HFE

- Treated in the evaluation of the basic HEP
- Examples include:
  - Self-review
  - Peer checking within a shift or after shift change
  - Shift Technical Advisor (STA) review
  - Procedure-related checks
- EPRI HRA Calculator – addressed via Cognitive Recovered and Execution Recovered modules - CBDTM recoveries applied consistent with EPRI TR-100259
  - Based on the time available for recovery, a minimum level of dependency applicable to recovery actions is suggested by the program
- ATHEANA - treated directly via conditional probabilities
  - When qualitative information is first converted into a quantitative estimate of the HEP, recovery of any initial error is addressed to the extent appropriate

Recovery at the cutset level

- PRA Standard definition – "Restoration of a function lost as a result of a failed system, structure, or component (SSC) by overcoming or compensating for its failure. Generally modeled by using HRA techniques."
- Adding cutset level recovery actions is common practice in PRA
- Credits other reasonable actions the operators might take to avoid severe core damage and/or a large early release that are not already specifically modeled

- Corresponding PRA Standard SRs: Part 2, HR-H
  Part 4, HRA-D1 and –D2

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Recovery, Dependency, Uncertainty Analysis

Slide 7

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Recovery at the cutset level (continued)

- For example, in PRA modeling of an accident sequence involving loss of all injection, it would be logical and common to credit operators attempting to locally align an independent firewater system for injection
- Failure to successfully perform such an action would subsequently be added to the accident sequence model
- Further lowers overall accident sequence frequency because additional failures of these actions would be required before the core is actually damaged

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Recovery, Dependency, Uncertainty Analysis

Slide 8

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Recovery versus repair (per RG 1.200)

- Recovery action is defined as:
  - a PRA modeling term representing restoration of the function caused by a failed system, structure, or component (SSC), by bypassing the failure.
  - Such a recovery can be modeled using HRA techniques regardless of the cause of the failure.
- Repair is defined as:
  - a general term describing restoration of a failed SSC by correcting the failure and returning the failed SSC to operability.
  - HRA techniques cannot be used since the method of repair is not known without knowing the specific causes

Recovery Analysis
Fire HRA

- Similar analysis process as for other fire HFEs
- Identification and Definition
  - Take note of existing Internal Event PRA recovery actions
  - From cutset review, identify risk-significant sequences with recovery potential
  - From fire and post-trip action procedures, use recovery-related steps to identify new recovery HFEs
  - Initial feasibility analysis
    - NUREG-1792, HRA Good Practices
    - NUREG/CR-6850 (EPRI 1011989)
    - NUREG-1921, Sections 3.5 and 4.3

Recovery Analysis

Fire HRA (continued)

- Qualitative Analysis
  - Review cutsets again to define key functional scenarios that the operators must address in each fire area (scenario)
  - Talk-through procedure-based recovery actions with operators or training personnel
- Quantification using same approaches
  - Screening
  - Scoping
  - Detailed (recommended to ensure thorough analysis of timing, PSFs and context)
- Incorporation into Fire PRA Model
  - Model-Specific (e.g., Recovery Rules file)

Recovery actions

Considerations for identification (per NUREG-1792)

- Cues are clear and provided in time to indicate need for recovery action(s) and failure(s) that need(s) to be recovered
- Sufficient time available for recovery action(s) to be diagnosed and implemented to avoid undesired outcome
- Sufficient crew resources exist
- There is procedural guidance
- Quality and frequency of training on recovery action(s)
- Equipment needed is accessible and in non-threatening environment (e.g., fire, extreme radiation)
- Equipment needed is available in context of other failures and initiator for sequence/cutset

Recovery actions

Not to be credited (per NUREG/CR-6850 [EPRI 1011989])

- Actions should not be credited as recoveries that:
  - require operators or other personnel to travel through fire or areas where fire effects (e.g., smoke, heat) are severe
  - involve restoring systems or equipment damaged by fire
  - have insufficient time available
  - require significant activity and/or communication among individuals while wearing SCBA (unless SCBA contains internal communication devices)

Recovery actions

Relaxation from original NUREG/CR-6850 guidance

- Reconsider Internal Event PRA assumptions (e.g., HRA recoveries of systems or components previously assumed failed)
  - re-evaluate WHY the component was assumed failed for internal events. ~~If it was for conservatism, then may want to consider it~~ to see if it can be considered for fire HRA
- Non-proceduralized HFEs can be credited, provided they meet the requirements of ASME/ANS SR HRA-H2
  - operator training includes the action, or justification for lack of procedures or training is provided
  - "cues" (e.g., alarms) exist to alert the operator to the recovery action
  - attention is given to the relevant PSFs
  - there is sufficient manpower to perform the action

Recovery considerations

- Details of the fire context in a specific fire area are well defined for most areas via the Fire PRA model iteration that factors in fire modeling and circuit analysis
- Fire scenario complexity can then be understood from the cutsets and fire area components failed
- Evaluation of HFEs is sensitive to the types of conditions that appear to the operators in the MCR
  - For example, fire impact can range from:
    - all conditions are normal
    - some degraded cues
    - significantly degraded cues and additional spurious operations

Recovery and use of procedures

- Since the procedures generally address one type of functional loss at a time, the operators responding to severe fire conditions will often be in multiple procedures to address multiple impacts that fires have on the system
- Need to review postulated recovery scenarios with operations and training personnel to verify procedure steps used and interactions between fire procedures and EOPs

Recovery Analysis consideration of circuit analysis *(per NUREG/CR-6850 [EPRI 1011989])*

- In some cases, electrical cable failures will result in permanent damage to electrical or mechanical equipment that precludes certain types of recovery actions
- For example, spurious operation of a valve due to a hot short that bypasses the valve's torque switch might cause permanent binding of the valve, precluding manual operation of the valve at a later time
- Cases of this nature should be documented and discussed with systems analysts to ensure recovery actions accurately reflect the prevailing conditions

- Corresponding PRA Standard SR: Part 4, HRA-D2, Note (1)

Qualitative definitions of fire recovery actions

Fire Initiated Scenario Type	Operator Objective (not recovery)	Selected HFE for recovery
Fire induced loss of DC power causes spurious ESFAS with normal cues	Override and control MSIS during fire, if nothing done then primary safeties lift in about 80 min.	OP FT control ESFAS and ADV given Fire
Fire induced trip with Loss of CST Makeup for AFW with normal cues	Provide makeup to CST 121 following a fire	OP FT Provide Makeup to CST given fire
Fire induced LOCA: Pzr valve 3/4 inch line open	Respond to loss of primary coolant and establish secondary cooling during fire	OP FT Depressurize to Containment Spray Pump Shutoff Head given fire with sample line open

Consideration of procedures and timing for fire recovery actions

Fire Scenario	Operator Actions for Fire	HFE Description	Time Required (diagnosis + execution)	Time Window (Tsw)	STD POST TRIP ACTIONS EOI SO23-12-1 R22	FIRE AOI SO23-13-21 R18
MSIS isolation (spurious from fire) with normal cues	Override and control MSIS during fire, if nothing done then primary safeties lift in about 80 min.	OP FT control ESFAS and ADV given Fire with **Normal Cues**	40	80	Step 8 VERIFY RCS Heat Removal criteria satisfied MSIS isolation OK use ADVs and AFW	Attachment 2- 12.0 AFW, MSS, MFW OPERATIONS then go to 3.0 ADV Operations (3.1.3) "When an ADV is needed, then OPERATE HV-8421 (for a Train A shutdown), or HV-8419 (for a Train B shutdown), in Local/Manual per SO23-3-2.18.1, Attachment for Local Manual Operation of HV-8419(HV-8421) Atmospheric Dump Valves."

Editing cutsets to address recovery

- The specific process of modifying models or results to account for recovery actions is PRA software-specific
- Some system, function, or sequence cutset equations may require editing before being used to quantify or merge event tree sequence equations
- Editing might include removal of disallowed cutsets, or the addition of recovery events
- Fire HRA analysts should work with the PRA model quantification team to understand the risk significant cutsets and how recovery actions are incorporated in the model in order to provide the appropriate inputs

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of fire human failure events
3. Qualitative analysis
4. Quantitative analysis
    a) Screening
    b) Scoping
    c) EPRI approach (detailed)
    d) ATHEANA (detailed)
5. Recovery analysis
6. **Dependency analysis**
7. Uncertainty analysis

Dependency Analysis
Evaluation Process

- Dependency evaluation
    - ASME/ANS PRA standard requires that multiple human actions in an accident sequence or cutset be identified, degree of dependency assessed, and joint HEP calculated
- Steps
    - Identify combinations of multiple operator actions in fire scenario (**regardless if screening, scoping or detailed quantification**)
    - Evaluate dependencies within scenario
    - Incorporate dependency evaluation into Fire PRA model
- Application
    - For Fire PRA, preliminary dependency analysis performed in combination with NUREG/CR-6850 (EPRI 1011989) Task 11, Detailed Fire Modeling and finalized as part of Task 14, Fire Risk Quantification

Applicable HLRs (per the PRA Standard)
Dependency

- HLR-AS-B: Dependencies that can impact the ability of the mitigating systems to operate and function shall be addressed (7 SRs)
- HLR-HR-G: The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence (8 SRs)
- HLR-QU-C: Model quantification shall determine that all identified dependencies are addressed appropriately (3 SRs)
- HLR-FQ-C: [Fire Risk] Model quantification shall determine that all identified dependencies are addressed appropriately (1 SR)

Dependency Analysis
Scope

- Similar to Recovery, Dependency within the same HFE is treated in the evaluation of the basic HEP through
  - Consolidation at the basic event level, e.g., miscalibrations of redundant channels are modeled in one basic event
  - THERP rules ranging from zero dependence (ZD) to complete dependence (CD)
- Fire HRA Dependency analysis primarily focuses on post-initiator HFEs occurring in the same cutset (i.e., pre-initiator HFEs are not affected by fire context)

- Corresponding PRA Standard SRs: Part 2, AS-B2, HR-G7 and -H3, QU-C1 and –C2; Part 4, FQ-C1

Dependency Analysis
Approaches

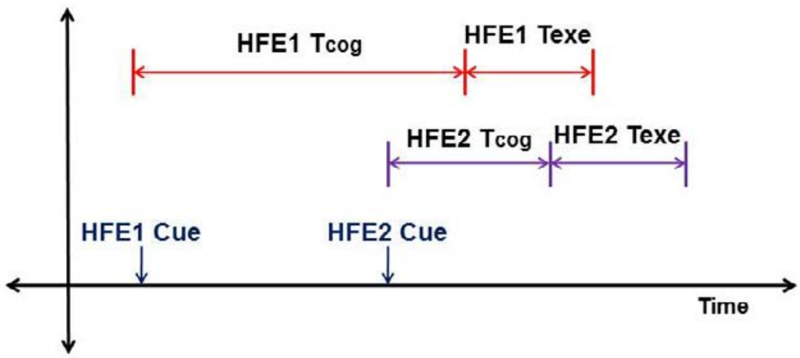
1. Use actual data from simulators
   - Highly resource intensive
2. Analyze each HFE combination in detail
   - Highly resource intensive
   - Best results
3. Assume complete dependence (only credit 1 HFE per cutset)
   - Not resource intensive
   - Impact on risk metric could be unacceptably over-conservative
4. Apply a systematic set of rules to assign different levels of dependence
   - Moderate resource requirements
   - Impact on risk metric could be acceptable
   - Recommended approach

Dependency Analysis
Definitions

- Dependence Importance (DI) of HEP Combination
  - Risk metric given all HEPs in a given chronological combination, except the first HEP, are set to 1.0
- Risk Achievement Worth (RAW) of HEP Combination
  - Risk metric given all HEPs in the combination are set to 1.0

Dependency Analysis
Definitions (Continued)

- Simultaneous
  - For two HFEs in a chronological sequence, if the cue or requirement for a successive HFE occurs before the preceding HFE can be completed, the HFEs are *simultaneous.*



Dependency Analysis
Basic Dependency Rules

- Dependence impact is one-directional in chronological order
- The THERP positive dependence model is adopted, i.e., failure of an event increases the probability of failure of a subsequent event
- The first HFE in a sequence is always independent
- In a chronological sequence, an HFE depends only on the immediately preceding HFE (given no common cognitive element)
- An HFE is independent of an immediately preceding success

Dependency Analysis
THERP Dependency Formulas

Dependence Level	Equation	Approximate Value for HEP < 0.01
Zero (ZD)	HEP	HEP
Low (LD)	(1+19 X HEP) / 20	0.05
Medium (MD)	(1+ 6 X HEP) / 7	0.14
High (HD)	(1 + HEP) / 2	0.5
Complete (CD)	1.0	1.0

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Recovery, Dependency, Uncertainty Analysis
Slide 36
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Dependency Analysis
THERP Dependency Formulas

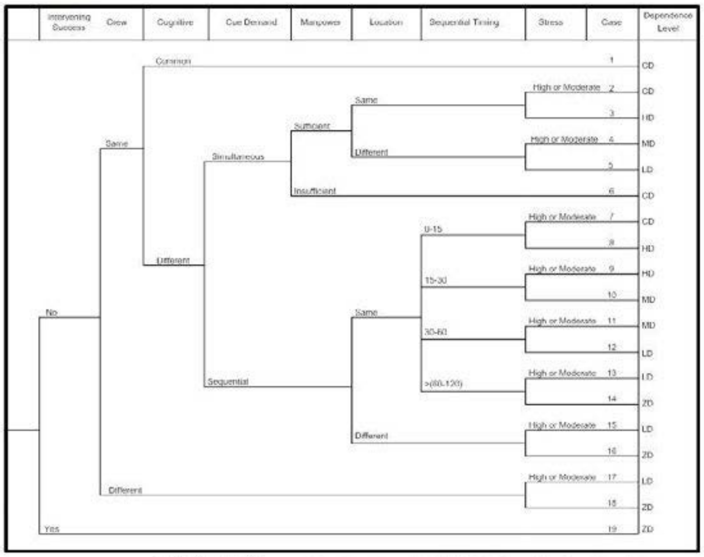
Dependence Level	Equation	Approximate Value for HEP < 0.01
Zero (ZD)	HEP	HEP
Low (LD)	(1+19 X HEP) / 20	0.05
Medium (MD)	(1+ 6 X HEP) / 7	0.14
High (HD)	(1 + HEP) / 2	0.5
Complete (CD)	1.0	1.0

Fire PRA Workshop, 2012, Bethesda, MD
Fire HRA – Recovery, Dependency, Uncertainty Analysis
Slide 36
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Dependency Analysis

Levels of Dependence

- **Dependency Factors**
  - Same Crew
  - Cognition (cues,procedures)
  - Simultaneity
  - Resources
  - Location
  - Timing
  - Stress



ATHEANA consideration of dependency

- Unsafe Action (UA): Actions inappropriately taken (~ EOCs), or not taken when needed (~ EOOs), by plant personnel that result in a degraded plant safety condition
- In ATHEANA, the potential for multiple UAs contributing to a particular HFE is considered
- Modeling and analyzing at the UA level provides the means to explicitly investigate the potential impact of different UAs on the plant response, as well as on other human actions
- ATHEANA considers dependency when there is a significant perceived dependency between a particular UA associated with the HFE and some other human failure modeled in the PRA (either upstream or downstream in the chain of events depicted by the PRA sequence)

ATHEANA consideration of dependency *(continued)*

- By breaking the HFE into UAs, the specific dependency can be modeled more appropriately and explicitly
- If multiple human failures in the same sequence are not foreseen during the initial quantification of the various UAs and their contexts, then as with any PRA/HRA methodology, there will be an obligation of the analysts to identify such combinations once the PRA is initially "solved" and the human error combinations can be readily identified
- Based on this information, HEP evaluation may have to be revisited/redone if the results of these evaluations are potentially significant contributors to the risk and sufficiently strong dependencies are considered to likely exist among certain HFE/UAs

Outline of the Presentation

1. Overview of the EPRI/NRC Fire HRA Guidelines
2. Identification and definition of fire human failure events
3. Qualitative analysis
4. Quantitative analysis
   a) Screening
   b) Scoping
   c) EPRI approach (detailed)
   d) ATHEANA (detailed)
5. Recovery analysis
6. Dependency analysis
7. **Uncertainty analysis**

Uncertainty Definitions
per the PRA Standard

- Uncertainty in the context of PRA and HRA is defined as the representation of the confidence in the state of knowledge about the parameter values and models used in constructing the PRA
- Uncertainty analysis: the process of identifying and characterizing the sources of uncertainty in the analysis, and evaluating their impact on the PRA results and developing a quantitative measure to the extent practical
- Guidance now available via NUREG-1855 and EPRI 1016737 on parameter and modeling uncertainties in PRA

Applicable HLRs (per the PRA Standard)
Uncertainty

- HLR-HR-G: The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence (8 SRs)
- HLR-QU-E: Uncertainties in the PRA results shall be characterized. Sources of model uncertainty and related assumptions shall be identified, and their potential impact on the results understood (4 SRs)
- HLR-UNC-A: The Fire PRA shall identify sources of CDF and LERF uncertainties and related assumptions and modeling approximations. These uncertainties shall be characterized such that their potential impacts on the results are understood (2 SRs)

Uncertainty Overview

- For fire HRA, uncertainties are addressed in the same manner as for internal events HRA
- The HRA should characterize the uncertainty in the estimates of the HEPs consistent with the quantification approach, and provide mean values for use in quantification
- In fire HRA, key assumptions may include timing or selections of performance shaping factors

- Corresponding PRA Standard SRs: Part 2, HR-G8, QU-E3

Qualitative issues contributing to FHRA uncertainty

- Some actions use screening values in the Internal Events PRA and these may be carried over to the fire HRA model as screening values
- Operators dealing with fire scenarios may use multiple Emergency and Abnormal Operating Procedures (EOPs and AOPs) at the same time to deal with multiple failure conditions, such as loss of inventory and loss of heat sink due to electrical cable failures
- Operators rely on the plant computer information to supplement the primary safety related instruments as diverse information sources. However, the computer systems are not usually considered in the fire model

Qualitative issues contributing to FHRA uncertainty (*continued*)

- The operators may not have specific procedures/plans for returning to the control room after a fire is out
- In case of fire, the MCR instrument response can degrade the flow of information to the operators
- Procedures dealing with fire are accurate in addressing Appendix R concerns, but can be complex for specific fire areas and may require some counterintuitive steps for the operators

Uncertainty Analysis

Potential Sources of HRA Modeling Uncertainty

Category	Potential Sources of HRA Modeling Uncertainty
Timing	Timing data inputs (T_{sw}, T_{delay}, T_{cog}, and T_{exe}) where T_{delay} can be impacted by uncertainty in the fire modeling such as the time to damage based on the selected heat release rates.
	Impact of timing variability on short or constrained timeframe events.
	Ex-control room action travel path changes as a result of fire location.
	Ability to obtain more than one operator's input to timing estimates.
	What to do with varying or conflicting operator input.
	Accuracy of operator timing estimates.
Dependency	Factors that would suggest an increased dependency level such as a common cognitive impact (both HFEs operating from the same cue).
Spurious and multiple spurious	Impact on cues such that the indications may not be accurate.
	Compelling indications or cues that may distract the operator from the modeled task.
	Geometry such that there is the potential for several spurious alarms or indications.
Stress	Is fire stress high?
Workload	Is fire event workload high?
Communications	Fire impacts to normal communications systems and process.
	Backup to radios available?
Training	Frequent and specific enough to be known when needed?
Procedures	Impact of single versus multiple procedures.
	Plant-specific emergency procedures not in standard format.
Crew dependency	Personnel availability and attentiveness during fire.

Uncertainty Analysis
HRA Data Uncertainty

- A number of activities may influence time to respond and contribute to diagnosis and execution timing uncertainty
- Situations or factors in fire context that may be difficult to recreate include:
  - MCR staff obtaining correct fire plan and procedures once fire location is confirmed
  - Collecting procedures, checking out communications equipment and obtaining any special tools or personnel protective equipment necessary to perform actions at local station
  - Traveling to necessary locations through smoke
  - MCR staff alerting and/or communicating with local staff implementing coordinated or sequential actions in multiple locations
  - Difficulties such as problems with instruments or other equipment (e.g., locked doors, a stiff hand wheel, or an erratic communication device)

Uncertainty in detailed HRA
EPRI HRA Calculator

- EPRI HRA Calculator approach to addressing uncertainty
  - is based on THERP Table 20-20 and guidance in THERP Chapter 7
  - applies the same error factors as for internal events
  - THERP's assessment of uncertainty
    - assumes a lognormal distribution
    - assigns an error factor solely based on the final HEP
  - Since the approach is not based on the initiating event, it can be applied to all initiators including fire
- Contrast with ATHEANA, which develops probability distributions using expert elicitation

EPRI HRA Calculator uncertainty categories for detailed analysis

Estimated HEP	REFERENCE	ERROR FACTOR
< 0.001	THERP Table 20-20	10
> 0.001	THERP Table 20-20	5
> 0.1	Mathematical convenience	1

Uncertainty in detailed HRA
ATHEANA

- ATHEANA uncertainty analysis is performed by developing probability distributions using expert elicitation
- The facilitator, with the assistance of the experts, puts forth two questions that progressively move the entire group from a qualitative evaluation to a quantitative estimate of the HEP and its uncertainty distribution:
  1. Given all the relevant evidence, how difficult or challenging is the action of interest for the scenario/context and why?
  2. Hence, what is the probability distribution for the HEP that best reflects this level of difficulty or challenge considering uncertainty?
- Applications of ATHEANA have found it useful to first provide a calibration mechanism for the experts to begin to interpret their qualitative conclusions into a probability

ATHEANA - Suggested Set of Initial Calibration Points for the Experts

Circumstance	Probability	Meaning
The operator(s) is "Certain" to fail	1.0	Failure is ensured. All crews/operators would not perform the desired action correctly and on time.
The operator(s) is "Likely" to fail	~ 0.5	5 out of 10 would fail. The level of difficulty is sufficiently high that we should see many failures if all the crews/operators were to experience this scenario.
The operator(s) would "Infrequently" fail	~ 0.1	1 out of 10 would fail. The level of difficulty is moderately high, such that we should see an occasional failure if all of the crews/operators were to experience this scenario.
The operator(s) is "Unlikely" to fail	~ 0.01	1 out of 100 would fail. The level of difficulty is quite low and we should not see any failures if all the crews/operators were to experience this scenario.
The operator(s) is "Extremely Unlikely" to fail	~ 0.001	1 out of 1000 would fail. This desired action is so easy that it is almost inconceivable that any crew/operator would fail to perform the desired action correctly and on time.

Uncertainty Analysis references

- NUREG-1855, "Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making," March 2009
- EPRI 1016737, "Treatment of Parameter and Model Uncertainty for Probabilistic Risk Assessments," December 2008
- NUREG-1880, "ATHEANA User's Guide," June 2007
- EPRI 1009652, "Guideline For Treatment of Uncertainty In Risk-Informed Applications," December 2005
- NUREG-1792, "Good Practices for Implementing Human Reliability Analysis (HRA)," Sandia National Laboratories, 2005
- NUREG/CR-1278, "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications," (THERP) Swain, A.D. and Guttmann, H. E., August 1983

NRC FORM 335 (12-2010) NRCMD 3.7 **BIBLIOGRAPHIC DATA SHEET** *(See instructions on the reverse)*	U.S. NUCLEAR REGULATORY COMMISSION	1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.) NUREG/CP-0303, Volume 4 EPRI 3002005205	
2. TITLE AND SUBTITLE Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)-2012 Volume 4 Module 4: Human Reliability Analysis (HRA)		3. DATE REPORT PUBLISHED MONTH: April	YEAR: 2016
		4. FIN OR GRANT NUMBER	
5. AUTHOR(S) K. Wright; P. Smith; F. Gonzalez; K. Hamburger; T. Rivera; D. Stroup		6. TYPE OF REPORT Technical	
		7. PERIOD COVERED (Inclusive Dates)	

8. PERFORMING ORGANIZATION - NAME AND ADDRESS (If NRC, provide Division, Office or Region, U. S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Division of Risk Analysis
U. S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research (RES)
Washington, DC 20555-0001

Electric Power Research Institute (EPRI)
3420 Hillview Avenue
Palo Alto, CA 94304

9. SPONSORING ORGANIZATION - NAME AND ADDRESS (If NRC, type "Same as above", if contractor, provide NRC Division, Office or Region, U. S. Nuclear Regulatory Commission, and mailing address.)

10. SUPPLEMENTARY NOTES

NRC–RES/EPRI Fire PRA Workshop conducted July 16–20, 2012, and September 24–28, 2012 in Bethesda, MD

11. ABSTRACT (200 words or less)

The U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research (RES) and the Electric Power Research Institute (EPRI) working under a memorandum of understanding (MOU) jointly conducted two sessions of the NRC–RES/EPRI Fire Probabilistic Risk Assessment (PRA) Workshop on July 16–20, 2012, and September 24–28, 2012, at the Bethesda Marriott in Bethesda, MD. The purpose of the workshop was to provide detailed, hands-on training on the fire PRA methodology described in the technical document, NUREG/CR-6850 (EPRI 1011989) entitled "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities." This fire PRA methodology document supports implementation of the risk-informed, performance-based rule in Title 10 of the Code of Federal Regulations (10 CFR) 50.48(c) endorsing National Fire Protection Association (NFPA) Standard 805, as well as other applications such as exemptions or deviations to the agency's current regulations and fire protection significance determination process (SDP) phase 3 applications.

This NUREG/CP documents both of the two sessions of the NRC-RES/EPRI Fire PRA Workshop delivered in 2012 and includes the slides and handout materials delivered in each module of the course as well as video recordings of the training that was delivered. This NUREG/CP can be used as an alternative training method for those who were unable to physically attend the training sessions. This report can also serve as a refresher for those who attended one or more training sessions and could also be useful preparatory material for those planning to attend future sessions.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)	13. AVAILABILITY STATEMENT
fire, risk-informed regulation, fire hazard analysis (FHA), fire safety, fire protection, nuclear power plant, probabilistic risk assessment (PRA), Fire modeling, circuit analysis, human reliability analysis	unlimited
	14. SECURITY CLASSIFICATION
	(This Page) unclassified
	(This Report) unclassified
	15. NUMBER OF PAGES
	16. PRICE

NUREG/CP-0303, Vol. 4 **Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) – 2012** April 2016

Module 4: Fire HRA