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Final Report

EPRI/NRC-RES Fire Human Reliability Analysis Guidelines

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

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

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EPRI/NRC-RES Fire Human Reliability Analysis Guidelines

EPRI 1023001 **NUREG-1921**

Final Report

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

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

EPRI Project Manager
S. Lewis

U.S. NRC-RES Project Manager
S. Cooper

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

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

Electric Power Research Institute

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ABSTRACT

During the 1990s, the Electric Power Research Institute (EPRI) developed methods for fire risk analysis to support its utility members in the preparation of responses to Generic Letter 88-20, Supplement 4, Individual Plant Examination of External Events (IPEEE). This effort produced a fire risk assessment methodology for operations at power plants that was used by the majority of U.S. nuclear power plants (NPPs) in support of the IPEEE program and by several NPPs overseas. Although these methods were acceptable for accomplishing the objectives of the IPEEE, EPRI and the U.S. Nuclear Regulatory Commission (NRC) recognized that the methods needed to be improved to support current requirements for risk-informed, performance-based (RI/PB) applications.

In 2001, EPRI and the NRC's Office of Nuclear Regulatory Research (NRC-RES), operating under a Memorandum of Understanding (MOU), embarked on a cooperative project to improve the state of the art in fire risk assessment to support a new risk-informed environment in fire protection. This project produced a consensus document, NUREG/CR-6850 (EPRI report 1011989)—*Fire PRA Methodology for Nuclear Power Facilities*—which addressed fire risk for at-power operations. NUREG/CR-6850 developed high-level guidance on the process for identifying human failure events (HFEs) and for including them in the fire PRA. The guidance also defined a process for assigning quantitative screening values to these HFEs. It outlined the initial considerations of performance shaping factors (PSFs) and related fire effects that may need to be addressed in developing best-estimate human error probabilities (HEPs). NUREG/CR-6850 did not, however, describe a method to develop best-estimate HEPs reflecting the PSFs and the fire-related effects.

In 2007, EPRI and NRC-RES (again working under the MOU) initiated another cooperative project related to fire PRA to develop explicit guidance for estimating HEPs for HFEs under fire conditions, building on existing human reliability analysis (HRA) methods. This report provides a method and associated guidance for conducting a fire HRA. The process includes the identification and definition of fire HFEs, qualitative analysis, quantification, recovery analysis, dependency analysis, and the treatment of uncertainty. The report also provides three approaches to quantification: screening, scoping, and detailed HRA. Screening is based on the guidance in NUREG/CR-6850, with some additional guidance for scenarios with long time windows. Scoping is a new approach to quantification developed specifically to support the iterative nature of fire PRA quantification. Scoping is intended to provide less conservative HEPs than screening but requires less time and effort than a detailed HRA analysis. For detailed HRA quantification, guidance has been developed on how to apply existing methods to assess fire HEPs.

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REPORT SUMMARY

In 2001, the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission's (NRC's) Office of Nuclear Regulatory Research (RES), operating under a Memorandum of Understanding (MOU), collaborated to improve the state of the art in fire risk assessment to support the new risk-informed environment in fire protection. This project produced a consensus document—NUREG/CR-6850 (EPRI report 1011989), *Fire PRA Methodology for Nuclear Power Facilities*—which addresses fire risk during operations at nuclear power plants. NUREG/CR-6850 developed high-level guidance on identifying and incorporating human failure events (HFEs) into the fire PRA and a method for assigning quantitative screening values to these HFEs. It also outlines the initial considerations of performance shaping factors (PSFs) and related fire effects that may need to be addressed in developing best-estimate human error probabilities (HEPs). However, NUREG/CR-6850 stops short of providing a method for developing best-estimate HEPs that account for these PSFs and fire-related effects.

In 2007, EPRI and NRC-RES embarked on another cooperative project under the original MOU to develop explicit guidance for estimating HEPs for HFEs under fire-generated conditions, building on existing human reliability analysis (HRA) methods. This joint report provides the methodology and guidance for conducting a fire HRA.

Background

This report is intended primarily for practitioners conducting a fire HRA to support a fire PRA. Because fire HRA builds on the internal events HRA models, the fire HRA analyst needs knowledge of HRA and the PRA used in the internal events model. This includes knowledge of HRA terminology, a general understanding of methodologies used for internal events HRA, familiarity with general plant operations including procedure usage, and an understanding of the internal events scenarios and fire PRA scenarios being modeled. A fire HRA typically requires a team effort because few individuals have the full range of expertise and knowledge necessary to complete the fire HRA.

The guidance in this report represents the state of the art in fire HRA practice. Certain aspects of HRA, especially in the area of quantification, continue to evolve and likely will see additional developments. Such developments should be easily captured within the overall analysis framework described in this report.

Objectives

This project was conducted to develop the methodology and supporting guidelines for estimating HEPs for human failure events following the fire-induced initiating events of a fire PRA.

Approach

The EPRI/NRC team defined the primary tasks for development of the fire HRA methodology: fire data review, fire HRA methodology and guideline development, and fire HRA review and testing. In developing the methodology, existing guidance was used or adapted where possible. Feedback on the use of HEP screening values from NUREG/CR-6850 was incorporated to update the screening HEPs. In addition, the team developed a new scoping fire HRA approach intended to produce less conservative HEPs than the NUREG/CR-6850 screening but requiring fewer resources than a detailed analysis. A draft document was created, subjected to peer review by a team of industry and NRC members, and distributed for public comment. The scoping approach was tested at two commercial nuclear power plants, and the draft guidelines were modified, revised, and developed further in the current report.

Results

This report reflects a state-of-the-art fire HRA approach. It offers fire HRA practitioners specific guidance for each step of the HRA process and relates the HRA process to fire PRA development, which is typically performed in parallel. This report builds on information documented in NUREG/CR-6850 regarding HRA and addresses the performance of HRA in a manner intended to satisfy the requirements of the combined PRA Standard. This fire HRA methodology is intended to provide an in-depth, realistic way to account for the key fire-induced influencing factors that impact human actions needed to prevent core damage or large early releases.

Applications, Value, and Use

This report provides more comprehensive guidance for performing HRA as part of a fire PRA than has previously been available. This is a final technical report developed based on a consensus process involving both EPRI and NRC-RES and is issued as both an EPRI report and a NUREG report. The HRA methods described address specific HRA methodological issues such as identification and definition, qualitative analysis, quantification, recovery, dependency, and uncertainty related to the probabilistic analysis of fire-initiated events.

This improved guidance for fire HRA supports the development and regulatory application of fire PRAs. It is anticipated that further improvements will be identified through the development of fire PRAs and through the application of these methods and guidelines, such as during the transition of a plant's fire protection program to a performance-based approach under National Fire Protection Association (NFPA) Standard 805.

Keywords

Fire risk
Human reliability analysis (HRA)
NFPA 805
Performance based
Probabilistic risk assessment (PRA)
Risk informed

PREFACE

Methods for fire probabilistic risk assessment (PRA) were used in the Individual Plant Examination of External Event (IPEEE) program to facilitate identifying a nuclear power plant's possible vulnerabilities to severe accidents. However, in order to make refined, realistic decisions for risk-informed regulation, fire PRA methods needed to be improved. More robust fire PRA methods will benefit licensee applications and U.S. Nuclear Regulatory Commission (NRC) review guidance with respect to many regulatory activities such as the risk-informed, performance-based fire protection rulemaking (endorsing National Fire Protection Association [NFPA] Standard 805). To address the need for improved methods, the NRC's Office of Nuclear Regulatory Research (NRC-RES) and the Electric Power Research Institute (EPRI) collaborated in 2001 under a joint Memorandum of Understanding (MOU) to develop NUREG/CR-6850, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*, a state-of-the-art fire PRA methodology.

The fire HRA guidance provided in NUREG/CR-6850 includes the process for identification and inclusion of the fire-related human failure events (HFEs), the methodology for assigning quantitative screening values to these HFEs, and the initial considerations of performance shaping factors (PSFs) and related fire effects that may need to be addressed in developing best-estimate human error probabilities (HEPs). HRA guidance in NUREG/CR-6850 (EPRI report 1008239) recommends the use of "detailed HRA methods" to address cases in which best-estimate HEPs are needed. However, existing detailed HRA methods did not provide fire-specific HRA guidance to systematically address fire-specific PSFs and related effects but relied on the judgment of the analyst(s) to select PSFs, evaluate the fire effects, define HFEs, and assess HEPs.

The NFPA 805 transition initiative has encouraged the development of additional guidance for performing HRA for fire PRA. This project builds on information documented in NUREG/CR-6850, Volume 2, Section 12, and addresses the development of HRAs—satisfying the combined PRA Standard, ASME/ANS RA-Sa-2009, Level 1 and Large Early Release Frequency (LERF) PRA Standard. This applies to at-power internal events, internal fire events, and external events for operating reactors.

This report is the third product of the collaboration between EPRI and NRC-RES and comes under the auspices of *MOU on Cooperative Nuclear Safety Research Between NRC and EPRI, Addendum on Fire Risk (Rev. 2)*. For this report, a more in-depth, realistic treatment has been developed to explicitly account for key fire-induced influencing factors that impact the human actions needed to prevent core damage or large early releases. It is anticipated that this guidance will be used by the industry as part of a transition to NFPA 805 and possibly in response to other regulatory issues such as multiple spurious operation and operator manual actions. This is the

first report addressing fire-related human reliability analysis for fire PRAs that goes beyond the screening level. As the methodology is applied at a wide variety of plants, the report may benefit from future improvements to better support industry-wide issues being addressed by fire PRAs.

This report does not constitute regulatory requirements. NRC-RES participation in this study does not constitute or imply regulatory approval of applications based on this methodology.

CITATIONS

This report was prepared by:

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA

Principal Investigator:
S. Lewis

Under contract to EPRI:

Scientech, a business unit of Curtiss-Wright Flow Control Company
16300 Christensen Road, Suite 300
Tukwila, WA 98188

Principal Investigators:
J. Julius
J. Grobbelaar
K. Kohlhepp

Science Applications International Corporation (SAIC)
1671 Dell Avenue #100
Campbell, CA 95008

Principal Investigators:
E. Collins
B. Hannaman

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, D.C. 20555

Principal Investigators:
S. Cooper
K. Hill

Under Contract to NRC-RES:

Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185

Principal Investigators:
J. Forester
S. Hendrickson

Applied Research & Engineering Sciences (ARES) Corporation
1440 Chapin Ave., Suite 390
Burlingame, CA 94010

Principal Investigator:
M. Presley

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Finally, we would like to thank the internal and external stakeholders who took the time to provide comments and suggestions on the draft of this report when it was published for public comment in the Federal Register (74 FR 65810) on December 11, 2009:

BWR Owners Group

David Helker, Exelon Generation Company, LLC

EPRI's Human Reliability Analysis (HRA) Users Group

PWR Owners Group

ACRONYMS

AC	Alternating Current
ACRS	Advisory Committee for Reactor Safeguards
AFW	Auxiliary Feedwater
ANS	American Nuclear Society
AOP	Abnormal Operating Procedure
AR	Annunciator Response
ARP	Alarm Response Procedure
ASD	Alternate Shutdown
ASME	American Society for Mechanical Engineers
ASP	Alternate Shutdown Panel
ATHEANA	A Technique for Human Event ANAlysis
ATWS	Anticipated Transient Without Scram
BHEP	Basic HEP
BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owners Group
CBDT	Cause-Based Decision Tree
CBDTM	Cause-Based Decision Tree Method
CCDP	Conditional Core Damage Probability
CCW	Component Cooling Water
CDF	Core Damage Frequency
CLERP	Conditional Large Early Release Probability

CO	Control Operator
CR	Control Room; Main Control Room
CS	Containment Spray
CSFST	Critical Safety Function Status Tree
CVCS	Chemical and Volume Control System
DC	Direct Current
DF	Dependent Failure
DHR	Decay Heat Removal
ECCS	Emergency Core Cooling System
EDG	Emergency Diesel Generator
EOC	Error of Commission
EOM	Error of Omission; EOO
EOP	Emergency Operating Procedure
EOO	Error of Omission; EOM
EP	Emergency Plan
EPRI	Electric Power Research Institute
ERF	Emergency Response Facility
ERFBS	Electrical Raceway Fire Barrier System
ESW	Essential Service Water
ET	Event Tree
EOF	Emergency Operations Facility
FEP	Fire Emergency Procedure
FPC	Fuel Pool Cooling
FR	Functional Restoration
FRP	Functional Restoration Procedure

HCR/ORE	Human Cognitive Reliability/Operator Reliability Experiment
HEP	Human Error Probability
HFE	Human Failure Event
HI	Human Interaction; also called Operator Action
HMI	Human-Machine Interface
HPI	High-Pressure Injection
HPSI	High-Pressure Safety Injection
HPSR	High-Pressure Safety Recirculation
HRA	Human Reliability Analysis
HVAC	Heating, Ventilating, and Air Conditioning
IE	Initiating Event
IEF	Initiating Event Frequency
IPE	Individual Plant Examination
IRT	Independent Review Team
ISLOCA	Interfacing Systems Loss-of-Coolant Accident
JPM	Job Performance Measure
LER	Licensee Event Report
LERF	Large Early Release Frequency
LLOCA	Large Loss-of-Coolant Accident
LOCA	Loss-of-Coolant Accident
LOOP	Loss of Offsite Power
LPI	Low-Pressure Injection
LPSD	Low Power and/or Shutdown
LPSI	Low-Pressure Safety Injection
LPSR	Low-Pressure Sump Recirculation

LTOP	Low Temperature Over-Pressurization
LWR	Light Water Reactor
MCR	Main Control Room; Control Room
MLOCA	Medium Loss-of-Coolant Accident
MOV	Motor Operated Valve
MSO	Multiple Spurious Operations
NFPA	National Fire Protection Association
NOP	Normal Operating Procedure
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRC-RES	NRC's Office of Nuclear Regulatory Research
NSSS	Nuclear Steam Supply System
NUREG	Nuclear Regulatory Commission document
OA	Operator Action; also called Human Interaction
OMA[1]	Operator Manual Action (typically in response to a fire)
OP	Operating Procedure
OSC	Operations Support Center
PM	Project Manager
PORV	Power-Operated Relief Valve
POS	Plant Operational State; Plant Operating State
PPE	Personnel Protective Equipment
PRA[2]	Probabilistic Risk Assessment; PSA

[1] In 10 CFR 50, Appendix R, these are local manual actions (outside the MCR).
In fire PRA, these may be operator actions added in response to a fire, such as to address spurious indications or alarms.

[2] PRA and PSA are often used interchangeably.

PSA	Probabilistic Safety Assessment; PRA
PSF	Performance Shaping Factor
PTS	Pressurized Thermal Shock
PWR	Pressurized Water Reactor
PWROG	Pressurized Water Reactor Owners Group
RAW	Risk Achievement Worth
RCS	Reactor Coolant System
RI/PB	Risk-Informed, Performance-Based
RNO	Response Not Obtained
RPS	Reactor Protection System
RT	Reactor Trip
RSP	Remote Shutdown Panel
RWST	Refueling Water Storage Tank
SCBA	Self-Contained Breathing Apparatus
SD	Shutdown
SDP	Significance Determination Process
SG	Steam Generator
SGTR	Steam Generator Tube Rupture
SISBO	Self-Induced Station Blackout
SI	Safety Injection
SLOCA	Small Loss-of-Coolant Accident
SSC	Systems, Structures, and Components
STA	Shift Technical Advisor
THERP	Technique for Human Error Rate Prediction
TSC	Technical Support Center

TT Turbine Trip

UB Upper Bound

UPS Uninterruptable Power Supply

V&V Verification and Validation

WOG Westinghouse Owners Group (now the Pressurized Water Reactor Owner Group PWROG)

1
INTRODUCTION

1.1 Background

Working jointly under a Memorandum of Understanding (MOU), the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission's Office of Nuclear Regulatory Research (NRC-RES) embarked on a cooperative program to improve the state of the art in fire risk studies. This program produced a joint document, EPRI 1011989/NUREG/CR-6850, *Fire PRA Methodology for Nuclear Power Facilities* [1][3]. For the human reliability analysis (HRA) task, NUREG/CR-6580 developed guidance for the following:

- The identification and inclusion in the fire PRA of the human failure events (HFEs)
- The assignment of quantitative screening values to these HFEs
- Initial considerations of performance shaping factors (PSFs) and related fire effects that may need to be addressed in developing best-estimate human error probabilities (HEPs)

NUREG/CR-6850 did not, however, identify or produce a method to develop best-estimate HEPs given the PSFs and the fire-related effects.

The authors of NUREG/CR-6850 recognized that further definition of appropriate methods (especially for developing best-estimate HEPs for HFEs in fire PRAs) and additional guidance for employing these methods were needed. In 2007, EPRI and NRC-RES embarked on another cooperative project to address these needs, using principles consistent with existing HRA methods. This document, which is the result of that cooperative project, provides a methodology and guidance for conducting a fire HRA. This process includes identification and definition of fire human failure events, qualitative analysis, quantification, recovery, dependency, and uncertainty. This report offers three approaches to quantification: screening, scoping, and detailed HRA. Screening is based on the guidance in NUREG/CR-6850 [1], with additional guidance provided in this report for scenarios with long time windows. Scoping is a new approach to quantification developed specifically to support the iterative nature of fire PRA quantification. Scoping is intended to provide less conservative HEPs than screening, but requires fewer resources than a detailed HRA. For detailed HRA quantification, guidance has been developed on how to apply existing methods to assess fire HEPs.

[3] When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following supplement as well:

Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.

1.2 Programmatic Overview

Under a joint MOU [2], NRC-RES and EPRI initiated a collaborative project to document the state of the art for conducting a fire PRA. This collaboration, known as the *Fire Risk Requantification Study*, brings together the wealth of information generated by the fire research programs at EPRI and NRC-RES in an environment that promotes the deliberation of differing technical views yet encourages consensus. This report is the result of this collaboration between EPRI and NRC-RES.

This report is the third product of the collaboration between EPRI and NRC-RES and comes under the auspices of *Memorandum of Understanding on Cooperative Nuclear Safety Research between NRC and EPRI, Addendum on Fire Risk (Rev. 2)*. As such, this project follows a process similar to that initiated as part of the MOU and followed in the previous two projects.

It is anticipated that this guidance will be used by the industry as part of a transition to National Fire Protection Association (NFPA) 805 [3] and possibly in response to other regulatory issues such as multiple spurious operation (MSO) and fire operator manual actions (OMAs). The transition to NFPA 805 is governed by Regulatory Guides 1.205 and 1.174 [4, 5] with guidance provided in several NEI documents [6–8].

However, because this is the first report addressing fire HRA for fire PRAs that goes beyond the screening level, the document may benefit from future improvements to more fully support industry-wide issues being addressed by fire PRAs. For example, because only a few NFPA 805 submittals have been made at the time of this report publication, improvements might be identified as part of the NFPA 805 transition process. Other improvements might be identified through separate, future PRA efforts such as HRA development projects (e.g., NRC's project to respond to SRM-M061020 [9] on HRA model differences). Examples of areas that might be improved include the following:

- Additional guidance on how to address plant-specific issues related to main control room (MCR) abandonment
- Broadened scope in defining and assessing the impact of fire-induced electrical faults such as fire-induced cable failures, including the impacts on equipment not part of the safe shutdown equipment list and potential spurious indications not directly related to cues for modeled operator actions in order to better assess the overall operator performance context

1.2.1 Objectives

The objective of this report is to develop methods and supporting guidelines for estimating human error probabilities for human failure events following fire-induced initiating events of a PRA. This report builds on existing HRA information such as HRA process and methods and the screening method included in NUREG/CR-6850 [1]. The guidance provided in this report is intended to be both an improvement of, and an expansion on, the limited guidance given in NUREG/CR-6850.

1.2.2 Technical Process Overview

The fire[4] HRA method and supporting guidelines were developed using a structured, systematic approach. The approach consisted of the following three primary tasks, each of which is summarized next:

1. Fire data review
2. Fire HRA method and guideline development
3. Fire HRA review and testing

1.2.2.1 Fire Data Review

This first task consisted of the following three distinct efforts:

- The requirements of a quality fire PRA as delineated in the fire portion of the combined PRA Standard [10] were reviewed. This review included the requirements in the fire section of the PRA Standard associated with the undesired response to spurious signals, such as instrumentation or component actuation, and is addressed in this report.
- Recent historical data from actual fire events were reviewed to determine whether additional failure modes or PSFs would need to be considered for fire scenarios beyond those identified in NUREG/CR-6850. This task built on previous, unpublished work conducted by Sandia Laboratories and the NRC. The fire event review confirmed the NUREG/CR-6850 development of PSFs, such that no additional factors needed to be added.
- Operator interviews were conducted and fire response procedures from PWR and BWR reactors were collected by EPRI in order to more fully understand the fire protection philosophy and the intended use of fire procedures in conjunction with normal emergency operating procedures during plant response to a fire.

1.2.2.2 Fire HRA Methodology and Guideline Development

The fire HRA development task used the insights from the fire data review as well as insights into HRA methods, based on NRC and industry experience. Insights from the development of NRC documents evaluating the current state of the art in HRA such as *Good Practices for Implementing Human Reliability Analysis* [11] and *Evaluation of Human Reliability Analysis Methods Against Good Practices* [12] were complemented with insights gained by EPRI in the development of HRA methods [13] and applying these methods using the PRA Standard [10]. The insights from these reviews identified the subtasks described in more detail in Section 2.2.

[4] The term *post-fire* is used in NUREG/CR-6850 to describe events that occur once a fire is detected. In this report, the term *fire* will be used instead of *post-fire*.

1.2.2.3 Fire HRA Review and Testing

This task consisted of an independent peer review, application testing, internal review by NRC and EPRI (in addition to the project team), and a public comment period. These subtasks are summarized as follows:

- **Independent technical review.** An independent technical review of the project deliverables was conducted before the document was released to the public for review and comment. This review was conducted by an independent review team (IRT) composed of experts in the subject areas of HRA, PRA, and/or fire. The specific missions of the IRT were to check the validity of the method and technical bases and to check the detail and clarity of the guidance to ensure the consistent and accurate application of the guidance.
- **Testing.** Portions of the fire HRA guidance developed in this document were tested through pilot applications at two plants, application as part of ongoing fire PRAs by the development team, and an owners group team independent of the developers. The objectives of the testing were to ensure that: 1) the method is robust and applies to all types of plants and the range of fire operator actions expected to be needed in a fire PRA, 2) there is sufficient and clear guidance for the users to render consistent application, and 3) the guidance produces reasonable values for human error probabilities (commensurate with the quantification method).
- **Public comment.** The draft for public comment of the Joint EPRI/NRC-RES Fire HRA Guidelines was published in December 2009. Public comments were accepted through March 2010. Four organizations provided public comments on the draft Fire HRA Guidelines: 1) the Boiling Water Reactor Owners Group (BWROG), 2) EPRI's HRA Users Group (HRA UG), 3) the Pressurized Water Reactor Owners Group (PWROG), and 4) Exelon. Each comment was tracked by the numbering system used by the commenter. Although most of these comments were primarily editorial in nature, they were used to update the document to its present version.

1.3 Scope

This report describes the process and technical bases for the performance of the HRA as part of a fire PRA. The report provides a complete reference for fire HRA as part of a PRA modeling the plant response to fire initiating events and specifically addresses quantification (for which there was limited guidance in NUREG/CR-6850 [1]). It is intended to be a stand-alone reference that supplements and extends the guidance in NUREG/CR-6850 Task 12 by providing additional guidance for the development of scoping and detailed human error probabilities for a fire HRA.

The purpose of fire HRA is to identify, characterize, and quantify events representing human failures used in the development and quantification of a fire PRA model. Fire HRA includes modifications to existing HFEs from the internal events (non-fire) PRA to incorporate fire impacts and scenarios as well as the analysis of new fire HFEs to be included in the fire PRA model. The scope of the fire HRA focuses on post-initiating event (dynamic) human failure events; these are grouped into the following categories:

- Internal events HFEs: events accounting for actions from, or associated with, the internal events PRA, typically using the normal (non-fire) set of emergency operating procedures.

- Fire response HFEs: events reflecting failures of actions added to the fire PRA, typically from fire procedures, fire response plans or pre-plans. These actions include those associated with MCR abandonment.
- HFEs corresponding to undesired response to spurious actuation or spurious instrumentation.

Pre-initiator (latent) HFEs, or latent human failure events, are not addressed in this report. All existing pre-initiator HFEs in the Level 1, internal events PRA model are independent of the initiating event and, therefore, independent of the fire initiating event as well. The existing pre-initiator HFEs do not need to be reanalyzed but should be retained in the fire PRA model because their impacts remain relevant to the conditional core damage probability (CCDP) and conditional large early release probability (CLERP). NUREG/CR-6850 [1] states the following:

> …the scope of this procedure does not include pre-initiator human failure events specifically related to fire systems, barriers, or programs. Undetected pre-initiator human failures such as improperly restoring fire suppression equipment after test, compromising a fire barrier, or incorrectly storing a transient combustible can all affect the fire risk. Tasks 6, 8, and 11 make use of industry-wide data that contains contributions from such human failures….

Therefore, pre-initiator HFEs in fire suppression systems are already included in the empirical data of NUREG/CR-6850. If suppression system fault trees are modeled explicitly, latent HFEs would be added using standard HRA modeling techniques. It should be noted that NUREG-1792 [11], documents that it is a good practice to review historical data for fire dampers. The multicompartment analysis portion of the fire PRA may consider mispositioned fire dampers, but there is no difference from the standard HRA methods for identification or qualitative and quantitative assessment. Therefore, latent HFEs are not addressed in this report.

Manual fire detection is not included in the HRA scope of this report. Manual fire detection is credited as a guaranteed success in continuously occupied areas; in other areas, the fire detection system and the operator response to the alarm are considered to determine detection probability.

NUREG/CR-6850 [1] uses a statistical evaluation of historical events to assign reliability estimates for fire suppression systems. Suppression is modeled by a set of curves showing the probability of non-suppression as a function of time available for suppression; there are curves for various types of fires and locations within a nuclear power plant (NPP). Because the fire suppression probability is addressed implicitly with data, it is not necessary for the HRA to explicitly model the fire brigade response as part of the HRA task. The NUREG/CR-6850 non-suppression curves are based on historical data for automatically actuated suppression systems. HFEs modeling the manual actuation of suppression systems would be accomplished following the guidance in this report.

1.4 Intended Audience and Prerequisite Expertise

This report is intended primarily for human reliability analysts involved in NPP fire PRAs. It is intended to serve the needs of a fire PRA team by providing a structured framework for conducting and documenting a fire HRA. This report pays particular attention to task interfaces and interactions between HRA and other disciplines in a fire PRA conducted following the approach outlined in NUREG/CR-6850 [1].

HRA involves qualitative and quantitative analysis of plant-specific, fire safe shutdown operator actions. Therefore, the analysis needs the participation of personnel knowledgeable of plant practices relating to operations, staffing, training, emergency preparedness, general emergency operating procedures, and fire-specific operating procedures as well as those familiar with plant-specific fire PRA modeling. Depending on the level of detail in the fire PRA (often related to the specific NUREG/CR-6850 task being supported), the multidisciplinary team will benefit from including deterministic fire modeling experts to describe the fire ignition and progression modeling as well as electrical expertise to describe the fire impact on electrical circuits, including open circuits and/or hot shorts. The HRA expert should help the PRA analyst identify and appropriately incorporate human actions in the plant fire safe shutdown response model.

1.5 Report Structure

This report is arranged in the following sections and associated appendices:

Section 1 (i.e., this section) delineates the objectives and scope of this report and provides the background information on the project tasks conducted in developing the fire HRA methodology and guidelines.

Section 2 defines the process framework for developing a fire PRA. It is intended to show to the user the various steps in conducting fire HRA and how these steps relate to fire PRA tasks.

Section 3 describes the methods for identifying actions and defining human failure events and provides guidance on how to model these HFEs in a fire PRA. This is an expansion of the guidance provided in NUREG/CR-6850, Volume 2, Section 12.5.1 [1].

Section 4 describes the qualitative attributes contributing to the quantification of HFEs, including PSFs. This is a major expansion of the guidance provided in NUREG/CR-6850, Volume 2, Section 12.5.5, including the introduction of the concept of feasibility.

Section 5 describes fire HRA quantification. Three approaches to quantification are offered: screening, scoping, and detailed HRA quantification. Screening human error probabilities are assigned based on a revision of the guidance provided in NUREG/CR-6850, Volume 2, Sections 12.5.2 through 12.5.4. The scoping approach is a new development, providing a more refined quantification than screening HRA but less refined than a detailed fire HRA. The detailed HRA approaches defined in this report are applications of either the EPRI HRA approach [13] or A Technique for Human Event ANAlysis (ATHEANA) [14] to the fire-specific human performance issues that need to be addressed in fire PRA.

Section 6 describes the process for addressing recovery actions, dependency, and uncertainty. First, recovery actions are addressed. The recovery actions considered in Section 6 are those that were not added to the fault trees and event trees as part of the initial, planned plant response. Instead, these actions are added at the sequence or cutset level to realign the affected system or to provide an alternative system, such that success of these actions would have prevented core damage and/or large early release. Next, Section 6 describes the steps to assess dependencies and conduct an uncertainty evaluation. Section 6 concludes with a description of uncertainty considerations for fire HRA.

Section 7 presents an overview of information to include in HRA documentation.

The appendices are presented in order of expected usage. Appendices A through D provide details on the methods and guidance presented in the body of this report. Appendices E and F provide background information developed in support of this report. Specifically:

- Appendix A presents the definitions of terms used in this report.
- Appendices B and C provide guidance for the detailed quantification of HFEs using
  - The EPRI HRA approach (cause-based decision tree [CBDT] [13] and human cognitive reliability/operator reliability experiment [HCR/ORE] [15] methods for the cognitive portion of the HFE and technique for human error rate prediction (THERP) [16] for the execution portion of the HFE), and
  - The ATHEANA method [14].
- Appendix D offers an evaluation of fire HRA analyses based on this guidance against the requirements of the fire portion of the combined PRA Standard [10].
- Appendix E contains a summary of the review and testing conducted in developing the fire HRA methods presented in this report.
- Appendix F provides the justification for the scoping HEPs.

1.6 References

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

   Note: When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following as well:

   Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.
2. Memorandum of Understanding (MOU) on Cooperative Nuclear Safety Research Between EPRI and NRC, Amendment on Fire Risk, Revision 1, 2001.
3. National Fire Protection Association (NFPA) Standard 805, *Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants*, 2001 Edition.
4. U.S. Nuclear Regulatory Commission. Regulatory Guide 1.205, *Risk-Informed Performance-Based Fire Protection for Existing Light Water Nuclear Power Plants*, May 2006.
5. U.S. Nuclear Regulatory Commission. Regulatory Guide 1.174, Rev. 1, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis*, November 2002.
6. NEI-00-01, Revision 2, *Guidance for Post-Fire Safe Shutdown Circuit Analysis*. Nuclear Energy Institute, Washington, D.C.: May 2009.
7. NEI-04-02, Revision 2, *Guidance for Implementing a Risk-Informed Performance-Based Fire Protection Program Under 10 CFR 50.48(c)*. Nuclear Energy Institute, Washington, D.C.: April 2008.
8. NEI-07-12, Revision 1, *Fire Probabilistic Risk Assessment Peer Review Process Guidelines*. Nuclear Energy Institute, Washington, D.C.: June 2010.

9. U.S. Nuclear Regulatory Commission, *Staff Requirements—Meeting with Advisory Committee on Reactor Safeguards, SRM M061020*, U.S. Nuclear Regulatory Commission, November 8, 2006, Washington, D.C.

10. 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*, The American Society of Mechanical Engineers, New York, NY, February 2009.

11. U.S. Nuclear Regulatory Commission. NUREG-1792, *Good Practices for Implementing Human Reliability Analysis*, April 2005.

12. U.S. Nuclear Regulatory Commission. NUREG-1842, *Evaluation of Human Reliability Analysis Methods Against Good Practices*, August 2006.

13. *An Approach to the Analysis of Operator Actions in Probabilistic Risk Assessment*. EPRI, Palo Alto, CA: 1992. TR-100259.

14. U.S. Nuclear Regulatory Commission. NUREG-1880, *ATHEANA User's Guide*, June 2007.

15. *Operator Reliability Experiments Using Nuclear Power Plant Simulators*. EPRI, Palo Alto, CA: 1990. NP-6937, as supplemented by EPRI TR 100259 [13].

16. U.S. Nuclear Regulatory Commission. NUREG/CR-1278, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications (THERP)*, A. D. Swain and H. E. Guttman, August 1983.

2
FIRE HRA FRAMEWORK

2.1 Introduction

The NFPA 805 [1] transition initiative has encouraged the development of guidance for performing HRA for fire PRA. This project builds on what is documented in NUREG/CR-6850 [2] (particularly Volume 2, Section 12) and addresses the development of human reliability analyses satisfying the combined ASME/ANS PRA Standard [3]. For this report, a more in-depth, realistic treatment has been developed to explicitly account for key fire-induced influencing factors that impact the human actions needed to respond to fire-induced initiating events in order to prevent or mitigate core damage or large early releases.

Although the process steps and concepts are the same for a fire PRA and internal (non-spatial) PRA, several key differences need to be addressed in the development of a fire PRA. Differences such as the impact of cable failures (on instruments and components) are summarized in Section 2.5. Other differences such as procedures and the impact on timeline development are described in Section 4. Therefore, it is useful to read Section 4 in conjunction with Section 2.

For fire HRA, this report recommends the process listed next and shown in Figure 2-1. This conceptual approach is based on the Systematic Human Action Reliability Procedure (SHARP1) framework for HRA [4] and the approach used in ATHEANA [5, 6]. The approach reflects the elements presented in the *Good Practices for Implementing Human Reliability Analysis*, NUREG-1792 [7]. The guidance in this report is also intended to support a fire HRA that would satisfy the relevant requirements in the combined ASME/ANS PRA Standard [3].

2.2 Fire HRA Process

The basic process for performing a fire HRA is outlined in NUREG/CR-6850 [2]. That process has been augmented by the guidance provided in this report. The following steps comprise the fire HRA process developed and used in this guideline:

1. Identify and define human failure events (HFEs):
   a. Identify and categorize HFEs:
      - Internal events HFEs used in the fire PRA
      - Fire response HFEs, including MCR abandonment
      - HFEs corresponding to undesired operator responses to alarms and indications
   b. Define the context and initial conditions for evaluating the HFE:
      - Initial assessment of the feasibility of the operator action

2. Perform the qualitative analysis:
   a. Assess the feasibility of the operator action
   b. Assess the context for impact on the HFE
   c. Assess performance shaping factors
   d. Develop an integrated timeline
   e. Develop narrative describing the initial conditions and the context for the HFE
   f. Incorporate plant-specific data:
      - Deterministic data such as fire growth and thermal-hydraulic data
      - Operator interviews
      - Experience review
3. Perform the quantitative analysis developing the HEP for an HFE, using one of the following:
   a. Screening approach
   b. Scoping approach to quantification
   c. Detailed approach to quantification
4. Perform recovery analysis:
   a. Identify and define relevant recovery actions
   b. Quantify HEP for recovery actions
5. Perform dependency evaluation:
   a. Identify combinations of multiple operator actions
   b. Evaluate dependencies
   c. Incorporate dependency evaluation into the fire PRA model
6. Perform uncertainty analysis
7. Complete documentation

Note: Although this fire HRA process is shown as sequential steps, in practice, almost all of these steps are iterative.

Figure 2-1 shows these high-level steps and relates them to HRA subtasks and other HRA methods and guidance. The following summarizes the changes in this report from the original NUREG/CR-6850 HRA development:

Identification and definition. The intent of the identification and definition step in the fire HRA process is unchanged from NUREG/CR-6850. However, this report introduces different categories of HFEs in order to better capture the influence of the procedures from which the actions are invoked. As part of the identification and definition step, the feasibility of the operator action is first assessed. The feasibility check will be an ongoing step throughout the fire HRA process (analogous to a continuous action step in the emergency operating procedures [EOPs]).

Qualitative analysis. For fire HRA, a qualitative analysis step (Section 4) has been established as a separate stand-alone step in the fire HRA process (as opposed to being embedded with other steps). In many methods, this step is implicitly considered during the identification and definition step. However, this step has proven to be important in the recent benchmarking exercises of HRA predictions with empirical data [8]. Consequently, this report has addressed qualitative HRA explicitly and has devoted an entire section to this step. The qualitative analysis presented in Section 4 provides a foundation for all steps in the HRA process; therefore, reading Section 4 in conjunction with the identification and definition steps presented in Section 3 is recommended.

Quantitative analysis. For fire HRA, this report provides three levels of quantification: screening, scoping, and detailed HRA. Although the levels are presented sequentially, it is not required that an analyst progress through them sequentially or use all of the methods. If the analyst finds the screening and scoping methods to be too conservative or limiting, the analyst is encouraged to use one of the more detailed HRA methods.

The screening methodology (Section 5.1) assigns quantitative screening values to the HFEs modeled in the fire PRA by addressing the unique conditions created by fires. In instances in which a less conservative analysis is required (i.e., when conservative screening values are unacceptable), the next stage presented is a scoping analysis. The screening approach presented in this report is largely unchanged from that in NUREG/CR-6850, except for some relaxation of HEP values for longer time windows.

The scoping analysis (Section 5.2) is a simplified HRA quantification approach developed specifically for this report that offers additional guidance beyond the screening analysis. Although it has similarities to a screening approach, the scoping quantification process requires a more detailed analysis of the fire PRA scenarios and the associated fire context as well as a good understanding of the many PSFs likely to influence the behavior of the operators in the fire scenario.

It is likely that, for any number of reasons, some actions will not be able to meet the criteria for the scoping HRA method. For such cases, a detailed HRA approach is required. NUREG/CR-6850 did not provide a detailed HRA approach suitable for addressing the impacts of fire effects on human performance. This report provides two such detailed fire HRA approaches in Appendices B and C: the EPRI HRA approach [9] and ATHEANA [5, 6], respectively.

Recovery, dependency, and uncertainty. These are aspects of fire HRA that were not addressed in NUREG/CR-6850. The report reminds the reader of existing guidance for internal events HRA/PRA, which should be applicable to fire HRA/PRA. In addition, the report identifies some fire-specific issues that will need to be addressed by fire HRA.

Fire HRA Process	Fire HRA Sub-Task	Relationship To Fire PRA Tasks and Other HRA Methodology Tasks
Identify and Define	• Identify HFEs From Internal Events • Identify Fire Response HFE (MCR abandonment is a subset) • Identify Undesired (response to spurious indication or actuation) operator actions • Define All HFEs (establish the context) • First Assessment of Feasibility of HFEs	• NUREG/CR-6850 Task 2, Task 5, Task 12 Post Fire HRA Screening • ASME/ANS PRA Standard Chapter 2 and Chapter 4 Requirements • NUREG-1880 Steps 1-4 • NUREG-1792 Section 4.3
Qualitative Assessment	• Develop narrative – (evaluate the impact of context) • Assess PSFs • Operator Interviews • Experience Review • Develop Narrative	• NUREG/CR-6850 Task 7, and Task 12, Fire HRA Screening • NUREG-1880 Steps 5-7 • NUREG-1792
Quantification	• Screening - Apply high level screening value to HFEs • Scoping - Quantification using scoping trees • Detailed- Quantification using EPRI approach or ATHEANA	• NUREG/CR-6850 Task 11, Task 7c, 7d, Task 14 Task 12 Fire HRA • ASME PRA Standard High Level Requirement HR-G • NUREG-1880 Step 8 • NUREG-1792 Section 5.1.3.
Recovery	• Include operator recovery actions that can restore function.	• NUREG/CR-6850 Task 11 • NUREG-1880 Step 7 and 8 • ASME PRA High Level Requirement HR-H
Dependency	• Identify combinations of multiple HFEs • Evaluate combinations • Address/incorporate combinations	• NUREG/CR-6850 Task 11 • NUREG-1880 Step 5-8 • ASME PRA High Level Requirement HR-G and HR-H
Uncertainty	• Address uncertainty and sensitivity	• ASME Standard HF-G9 • ATHEANA Step 8 • NUREG-1792 • NUREG-1855 • EPRI 1016737
Documentation	• Document HRA process • Document HRA key assumptions • Document HRA results	• NUREG 1792 • ASME PRA High Level Requirement HR-I • ANS Fire PRA Standard HRA-E1

Figure 2-1
Fire HRA process overview

2.3 Relationship to Other Fire PRA Tasks

Fire HRA is an iterative process developed in conjunction with a fire PRA. Fire PRA is a series of successive quantifications starting at the screening level and becoming more and more detailed. As the fire PRA evolves, the fire HRA will also evolve. As such, the inputs to the fire HRA potentially come from several fire PRA tasks listed in NUREG/CR-6850 [2]. Similarly, the fire HRA output feeds several NUREG/CR-6850 fire PRA tasks, including various levels of fire PRA quantification (e.g., NUREG/CR-6850 Tasks 7, 8, and 11).

Figure 2-2 shows, in total, how the fire HRA task (NUREG/CR-6850 Task 12) is connected with the other NUREG/CR-6850 fire PRA tasks. The solid lines are as depicted in NUREG/CR-6850 and represent either the end results or the inputs to the fire HRA (Task 12). The dotted lines have been added for completeness; the information is not necessarily considered an input or end result according to NUREG/CR-6850. For example, the timing information necessary for the HFE quantification may come from an intermediate step such as Task 11 but is not explicitly identified as an output of Task 11. NUREG/CR-6850 provides the following list of how the fire HRA is linked to other NUREG/CR-6850 fire PRA tasks:

- NUREG/CR-6850 Task 2, Fire PRA Component Selection. This task identifies fire-scenario mitigating equipment and diagnostic indications of particular relevance to human actions modeled in the fire PRA. Task 12 identifies the human actions needed in the model. Tasks 2 and 12 are iterative because identified human actions may imply additional equipment and diagnostic indications, which need additional human actions. Note that the equipment and indications will involve those needed for the potential success of actions required by EOPs or fire procedures and those whose failure (including spurious events) during a fire can influence operators to isolate or reposition critical equipment into a less desirable position.
- NUREG/CR-6850 Task 5, Fire-Induced Risk Model, provides a list of human actions already included as basic events in the portions of the internal events PRA modeled in the fire PRA. These actions will be reviewed and revised (if needed) in the Task 12 fire HRA. New human failure events identified in Task 12 (such as in a review of fire procedures) will be added to the fire PRA model as part of NUREG/CR-6850 Task 5.
- NUREG/CR-6850 Task 7, Quantitative Screening. The fire HRA in NUREG/CR-6850 Task 12 provides screening human error probabilities used in performing the quantitative screening or first quantification conducted in NUREG/CR-6850 Task 7. The Task 7 quantification results will provide feedback to Task 12 based on the accident sequences or cutsets and accompanying CCDPs. The feedback will identify fire scenarios and fire HFEs needing a more detailed best-estimate analysis to obtain more realistic core damage frequencies (CDFs) and/or large early release frequencies (LERFs).
- Knowledge from supporting tasks such as NUREG/CR-6850 Task 3, Fire PRA Cable Selection; Task 9, Detailed Circuit Failure Analysis; and Task 10, Circuit Failure Mode Likelihood Analysis, will prove useful to the fire HRA. In these tasks, the associated cable and circuit analyses help determine the potential for equipment failures as well as spurious operations and indications that the operators may face during a fire event. This information will establish which screening HEPs are selected as well as the best-estimate quantification of the more important HFEs. As part of the iterative nature of PRA, in some cases it will be desirable to perform some of the more detailed tasks (i.e., Tasks 9 and 10) as input to Task 12 to establish the best screening HEPs to carry out Task 7 most efficiently.

- Knowledge from NUREG/CR-6850 Task 8, Scoping Fire Modeling, and NUREG/CR-6850 Task 11, Detailed Fire Modeling, provides details on the fire modeling of various areas and can be useful in defining scenario-specific factors affecting HRA. These factors impact the assignment of screening HEPs as well as scoping and best-estimate quantification of the more important HFEs. For example, the potential for adverse environments and timing information relative to equipment damage comes from these two tasks. As part of the iterative nature of PRA, in some cases it will be desirable to perform portions of NUREG/CR-6850 Tasks 8 or 11 as input to Task 12 to establish the best screening HEPs to carry out Task 7 more efficiently.
- Ultimately, the final products of NUREG/CR-6850 Task 12—including the HFEs to be modeled, some screening HEPs, and scoping and best-estimate quantification of certain HFEs—are inputs into the final risk quantification performed under NUREG/CR-6850 Task 14, Fire Risk Quantification.

Compared to the preceding discussion, Table 2-1 provides a more detailed mapping of each NUREG/CR-6850 step and the interrelationships among fire PRA tasks, fire HRA tasks, and the associated elements and requirements of the combined PRA Standard. This table gives the analyst an understanding of the information provided to the fire HRA task from other fire PRA steps and which outputs from the fire HRA are fed to the larger fire PRA.

Table 2-1 depicts the nominal, expected representation of the flow of work between fire PRA tasks and fire HRA tasks. In other words, the table was developed from the perspective that a fire PRA is logically and sequentially developed; it is not intended to define requirements for interrelationships. For the development of a plant-specific fire PRA or in applying the fire PRA to a particular issue, there are likely to be cases in which steps are conducted in parallel or with varying levels of detail in the fire PRA information (e.g., missing data or data that are being developed). In these cases, one could apply a different HRA method, for example, a screening HEP during the quantification of a detailed scenario. In this case, the overall quantification may be acceptable (e.g., PRA Standard Capability Category I), or it may lead to further refinement if best-estimate results (e.g., PRA Standard Capability Category II) are needed.

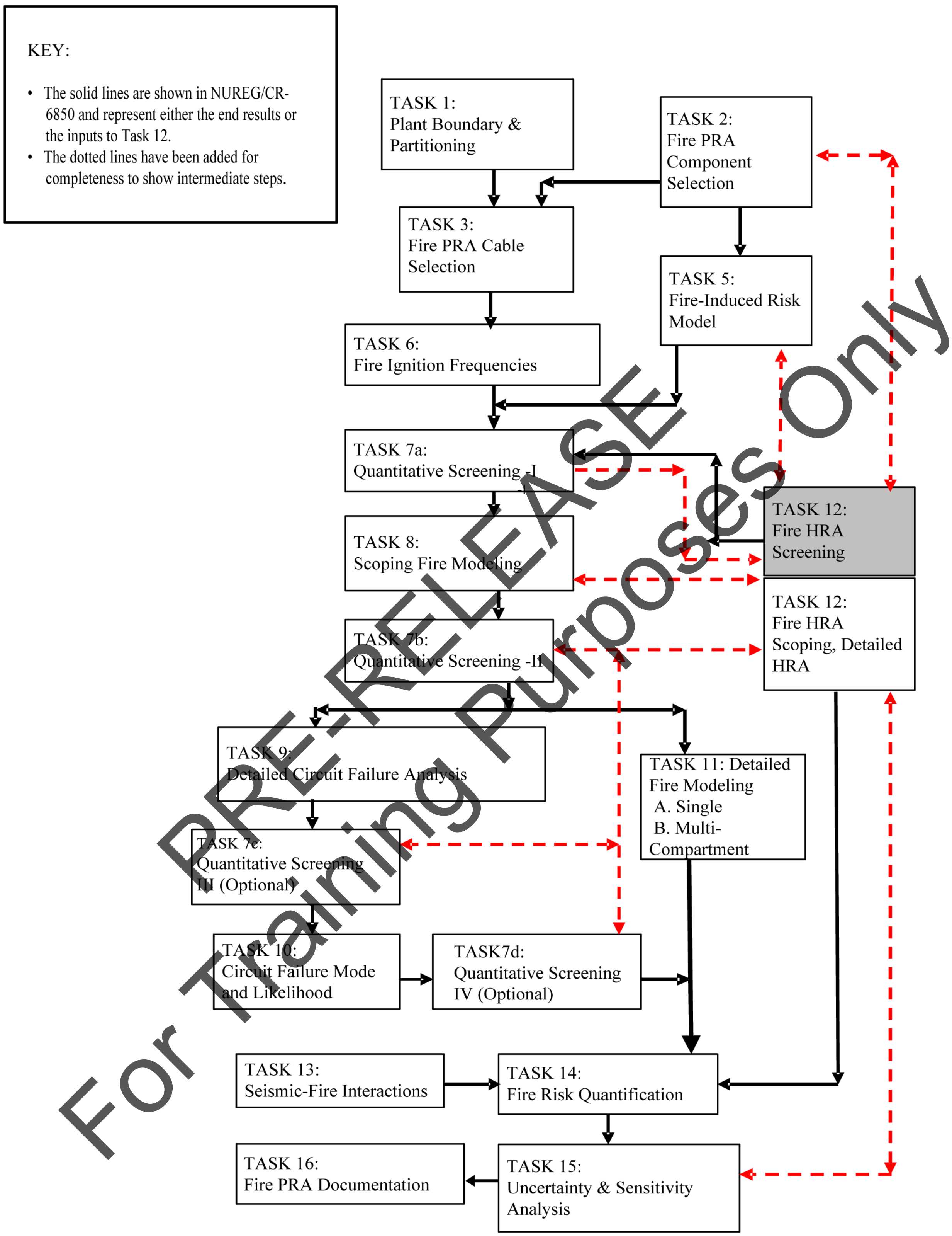

Figure 2-2
Mapping of fire HRA Task 12 to NUREG/CR-6850 PRA Tasks

Note: Tasks 7c and 7d were added based on discussion in NUREG/CR-6850 [2].

Table 2-1
Fire PRA/Fire HRA task interfaces

NUREG/CR-6850 [2] Fire PRA Task	Combined ASME/ANS Fire PRA Standard [3] Element (Category II)	Fire PRA Feeds Information into Fire HRA	Fire HRA	Fire HRA Feeds Information into the Fire PRA	Additional Notes
1. Plant Partitioning	PP (general)	Compile a list of areas to be quantified in the fire PRA.	Not applicable (N/A).	N/A.	This task provides input to the fire HRA by defining the fire areas, boundaries, and locations.
2. Component Selection	ES (general)	Identify fire-induced initiating events modeled in the fire PRA. Identify components modeled in the fire PRA.	Determine operator actions associated with the fire PRA initiating events. Determine components credited in the fire HRA.	The fire HRA identifies cues for the modeled fire PRA operator actions; these are translated into associated instruments for use in Task 2.	Starts with "existing EOP" actions from internal events PRA and then adds HFEs for fire-failed indication (if appropriate). Components not included in Task 2 likely do not have their cables traced.
	ES-B04	Compile a list of power supplies associated with instruments credited in the fire PRA.	Address/include the failure of instrument power supplies in fire-induced failures of the instruments and in spurious operation of the instruments.	N/A.	Fire PRA needs to include the impact of power supplies on modeled instrumentation.
	ES-C High-level requirement	Identify instrumentation impacting reliability of operators, including impact on cues for operator actions and impact of spurious instrumentation failure.			

Table 2-1
Fire PRA/Fire HRA task interfaces (continued)

NUREG/CR-6850 [2] Fire PRA Task	Combined ASME/ANS Fire PRA Standard [3] Element (Category II)	Fire PRA Feeds Information into Fire HRA	Fire HRA	Fire HRA Feeds Information into the Fire PRA	Additional Notes
2. Component Selection (contd.)	ES-C01	Identify instrumentation credited as cues for operator actions.	Identify each cue from the start of the fire or reactor trip, including procedure transfers, to the modeled cues associated with the HFEs.	Identify specific instruments associated with the cues.	Initially developed using the cues associated with the HFEs from the internal events PRA modeled in the fire PRA and expanded to include fire response actions.
	ES-C02 (failure modes other than spurious)	Identify instruments affected by fire-induced failure, where fire may fail any single instrument.	Consider and include the impact on the fire HRA if instrumentation is partial/degraded or failed.	N/A.	If fire fails one train, credited instrumentation needs to have redundancy to allow credit for an operator action.
	ES-C02 (spurious failures)	Identify instruments affected by fire-induced failure, where fire may cause a spurious failure in a single instrument that may impact operator response, even if the instrument is not credited in the fire PRA.	Review/identify spurious instrumentation failures that lead to undesired operator responses.	Potentially add new component failure modes into the fire PRA as well as the potential for new recovery action.	Capability Category III addresses up to and including two simultaneous spurious events.

Table 2-1
Fire PRA/Fire HRA task interfaces (continued)

NUREG/CR-6850 [2] Fire PRA Task	Combined ASME/ANS Fire PRA Standard [3] Element (Category II)	Fire PRA Feeds Information into Fire HRA	Fire HRA	Fire HRA Feeds Information into the Fire PRA	Additional Notes
3. Cable Selection	CS (general)	Select the specific cables associated with instrumentation and components credited in the fire PRA in order for these cables to be traced or located.	N/A.	N/A.	Used as input to the HFE definition and quantification. This task includes cable tracing so that the impact of fire on instrumentation is known for each area.
4. Qualitative Screening	QLS (general)	Perform area review and screening based on qualitative impact. Areas with operator action impact are retained.	N/A.	N/A.	N/A.

Table 2-1
Fire PRA/Fire HRA task interfaces (continued)

NUREG/CR-6850 [2] Fire PRA Task	Combined ASME/ANS Fire PRA Standard [3] Element (Category II)	Fire PRA Feeds Information into Fire HRA	Fire HRA	Fire HRA Feeds Information into the Fire PRA	Additional Notes
5. Fire-Induced Risk Model	PRM (general)	Perform event tree/accident progression.	Identify operator actions, typically EOP actions from the internal events PRA, in the event trees; the event trees define the PRA context.	Model basic events to represent human failures in the fire PRA.	Context includes the initiating event and the preceding successes and failures on the event tree.
		Develop fault tree/system models.	Include operator actions in the fault trees. These can be EOP actions from the internal events PRA, fire response actions (typically recovery or prevention of fire-induced hardware failures), undesired spurious actions that disable components, and recovery actions.	Model basic events to represent human failures in the fire PRA.	N/A.
		Determine success criteria.	Obtain timing data such as time of cues or system time window from thermal-hydraulic analyses, which can be from the internal events PRA or specific analyses for fire-induced conditions.	Operator actions credited in the fire PRA can influence the plant response modeled in the thermal-hydraulic analyses.	Context includes the system time window from thermal-hydraulic analyses.
		Data.	Incorporate HEPs into the fire PRA for each modeled human failure event.	Human error probabilities (HEPs) are developed in HRA quantification (Task 12).	N/A.

Table 2-1
Fire PRA/Fire HRA task interfaces (continued)

NUREG/CR-6850 [2] Fire PRA Task	Combined ASME/ANS Fire PRA Standard [3] Element (Category II)	Fire PRA Feeds Information into Fire HRA	Fire HRA	Fire HRA Feeds Information into the Fire PRA	Additional Notes
6. Ignition Frequencies	IGN (general)	Develop ignition sources and frequencies into initiating events, independent of fire HRA.	N/A.	N/A.	This task does not involve HRA.
7. Quantitative Screening	QNS (general)	Perform area screening based on quantitative impact, typically with all components and cables in an area failed.	Typically use screening HRA. Conservative, screening HEPs are typically used to capture the fire impacts and ensure that bounding values used in quantitative screening eliminate areas from further analysis.	HEPs for modeled HFEs.	Also called *first quantification* or *whole-room burnup*.
8. Scoping	Subsumed into FSS (in general)	Refine whole-room burnup by crediting severity factors.	Typically use scoping HRA. Refinement of screening HEPs based on looking more closely at the area geometry and associated fire source/target impacts.	Refine HEPs for modeled HFEs.	Fire impacts are refined.

Table 2-1
Fire PRA/Fire HRA task interfaces (continued)

NUREG/CR-6850 [2] Fire PRA Task	Combined ASME/ANS Fire PRA Standard [3] Element (Category II)	Fire PRA Feeds Information into Fire HRA	Fire HRA	Fire HRA Feeds Information into the Fire PRA	Additional Notes
9. and 10. Circuit Failure Analyses	CF (general)	Determine which circuits are susceptible to fire-induced failures and the likelihood of occurrence.	May eliminate the need for operator actions if components are not susceptible to spurious failures.	N/A.	This task generally does not involve HRA. However, as the electrical impact on model components is refined, there may be HRA changes. For example, valves susceptible to operability issues such as Information Notice 92-18 [10] may be identified.
11. Detailed Fire Modeling	FSS (general)	Refine Tasks 7 and 8.	Typically use detailed fire HFE quantification, but may use screening and scoping HRA methods as well.	Refine HEPs for modeled HFEs.	Refinement could be on an area basis or scenario basis.
	a. Individual areas All FSS (general) except FSS-B and FSS-G	Develop detailed fire scenarios, with fire growth models and specific impacts.	Identify scenario-specific performance shaping factors.	Refine HEPs for modeled HFEs.	N/A.

Table 2-1
Fire PRA/Fire HRA task interfaces (continued)

NUREG/CR-6850 [2] Fire PRA Task	Combined ASME/ANS Fire PRA Standard [3] Element (Category II)	Fire PRA Feeds Information into Fire HRA	Fire HRA	Fire HRA Feeds Information into the Fire PRA	Additional Notes
11. Detailed Fire Modeling (contd.)	b. Main control room FSS-B (general)	Develop main control room abandonment scenarios.	Typically a NUREG/CR-6850 screening approach is used.	HEPs for modeled HFEs.	May be refined, scenario-specific HEPs (similar to those for Task 11a) for evaluation of individual panel burnup.
	c. Multi-compartment analysis FSS-G (general)	Develop multi-compartment scenarios in a successive screening approach.	Fire HRA commensurate with the level of detail in the quantification (e.g., Task 7 HEPs for whole area burnup) and detailed HEPs according to Task 11a for detailed scenarios).	HEPs for modeled HFEs.	N/A.
12. Fire HRA	HRA	Perform fire PRA modeling of area, whether on a whole-room basis (Task 7), scoping refinements (Task 8), or detailed scenarios (Task 11).	Addressed in this document: • Identification/ definition of HFEs. • Qualitative analysis. • Quantification. • Dependency analysis. • Recovery and uncertainty.	HEPs for modeled HFEs plus the factors listed above such as instrumentation and components needed to support the credited actions. HRA also contributes to result insights both qualitatively (such as procedures, training, and timing) and quantitatively (such as the list of important operator actions).	This table addresses fire HRA-specific requirements; for new HFEs, the general requirements for HFEs from Chapter 2 of the PRA Standard apply.

Table 2-1
Fire PRA/Fire HRA task interfaces (continued)

NUREG/CR-6850 [2] Fire PRA Task	Combined ASME/ANS Fire PRA Standard [3] Element (Category II)	Fire PRA Feeds Information into Fire HRA	Fire HRA	Fire HRA Feeds Information into the Fire PRA	Additional Notes
13. Seismic-Fire Interaction	SF (general)	Perform a qualitative review of post-seismic fire response.	Beyond the scope of this report.	Beyond the scope of this report.	This task generally does not involve HRA, but post-Fukushima evaluations could change this.
14. Integrated Risk	FQ (general)	Combine the overall fire PRA using results from all previous tasks.	See notes on Tasks 7, 8, and 11.	See notes on Tasks 7, 8, and 11.	N/A.
15. Uncertainty	UNC (general)	Use fire HRA input for fire PRA parametric data uncertainty and sources of modeling uncertainty.	HEP distribution data for evaluation of fire PRA parametric data uncertainty. Identification of sources of modeling uncertainty.	HEP distribution data for evaluation of fire PRA parametric data uncertainty. Identification of sources of modeling uncertainty.	N/A.

2.4 General Assumptions

The work performed under these guidelines assumes the following:

1. The fire PRA and fire HRA are concerned only with fires that cause an initiating event that leads to a reactor trip or a requirement for a reactor trip or manual shutdown. Such fires are considered obvious to detect. Smaller fires may not be obvious to detect, but their consequences would be much less significant—and, if no reactor trip occurs, they are not relevant to the fire HRA. This assumption is consistent with the following assumptions in NUREG/CR-6850 [2]:
   - The crew is aware of the fire location within a short time (i.e., within the first ~10 minutes of a significant indication of non-normal condition by fire alarms, multiple equipment alarms, and automatic trip).
   - The crew is aware of the need for plant trip (if it is not automatic).
   - The crew is aware of the need to implement a fire brigade.
   - The crew is aware of the potential for unusual plant behavior as a result of the fire. 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. Therefore, assigning one to the fire brigade does not diminish the control room capability below what is required.
2. All of the required fire protection safe shutdown actions, either from the Appendix R [11] program or from NFPA 805 [1] safe shutdown analysis, are proceduralized in the plant fire response procedures. It is not within the scope of this report to identify new Appendix R or NFPA 805 safe shutdown actions required to satisfy the plant's fire protection program requirements. This report addresses the identification of operator actions required for fire PRA; these actions may or may not be added to the Appendix R/NFPA 805 safe shutdown list.
3. In general, a fire anywhere in the plant introduces new accident contextual factors and potential dependencies among the human actions beyond those typically treated in the internal events PRA. These new factors and dependencies will mildly or significantly increase the potential for unsafe actions during an accident sequence and will be addressed in the procedure. They include, for instance, potential adverse environments (e.g., heat and smoke), possible accessibility and operability issues, use of fire procedures, potential spurious events associated with both diagnostic and mitigating equipment, and increased demands on staffing and workload.
4. As stated previously, it is assumed that the crew is aware of the fire location within a short period of time (~10 minutes). After the crew is aware of the location, the fire brigade will work quickly to extinguish the fire. For HFEs in which several hours are available after reactor trip to perform the action, it is assumed that the action is time independent of the fire and that fire impacts will have little, if any, effect on operator performance.
5. The objective of the MCR crew is to manage the active power control, injection, and heat removal systems to achieve safe shutdown with no damage to the core given the fire.

2.5 Fire-Induced Cable Failure(s) and Electrical Fault(s)

Fire PRAs developed using the guidance of NUREG/CR-6850 [2] generally include a more detailed treatment of fire-induced electrical cable failures than fire PRAs developed before 2000. Specifically, the potential impact of fire-induced cable failures causing spurious component and instrument impacts has been explicitly considered in NUREG/CR-6850 fire PRAs. This section summarizes the various ways in which fire-induced cable failures are typically modeled in a fire PRA as well as their treatment in the fire HRA.

Fire-induced failures of single and/or multiple cables have a wide range of potential impact on the plant and subsequently on the fire PRA, as shown in Table 2-2. The following are examples of the types of fire damage:

- Spurious actuation of equipment (e.g., opening or closing of valves and starting or stopping of pumps)
- Spurious actuation of alarms (e.g., alarm lights and audible alarms before actual plant conditions reach alarm set points)
- Failures of alarms to actuate (even when plant conditions reach alarm set points)
- Spurious indications that provide misleading information (with the specific indication failure mode dependent on the type of indication [e.g., gauges] as well as the cable type and its associated fire damage), for example:
  - Readings that are too high, too low, or otherwise inconsistent with plant parameters
  - Trends that are inconsistent with plant parameters

This fire damage is, of course, in addition to the random equipment failures caused by traditional modes (e.g., failure to start or failure to run). It is important for the HRA analyst to understand the overall picture of plant damage based on the fire-induced failures as well as the random equipment failures when developing the context of the human failure event. Guidance on this is provided in Section 4. Most if not all of the plant damage information will be developed by other analysts involved in the fire PRA, and the fire HRA analyst will likely need to request input information that is not readily available.

Some fire areas will have little to no impact on the components needed to safely shut down the plant while other areas will be highly complex, such as failing all of the motor-operated valves in one train while the pumps still have power. For areas with many fire-induced cable failures, the state of the art in fire HRA currently has difficulty in fully capturing the impacts of these failures during the quantification of the HFE. Section 4.10 provides guidance on qualitatively treating the operator response to fire-induced cable failures such as spurious actuation.

The issue of fire-induced cable failures has a broader impact on the fire PRA than the fire HRA quantification of highly complex areas and scenarios. This section systematically identifies the different ways in which fire-induced cable failures appear in a fire PRA model. Table 2-2 describes the variety of ways that fire-induced cable failure(s) can impact the plant, describes how the plant impact is typically addressed in a fire PRA and fire HRA, and summarizes the treatment of the category of spurious failure(s) in this document. As such, the table summarizes the scope of the fire-induced cable failure(s) and electrical fault(s) treatment for operator actions considered in this report.

Table 2-2
Mapping fire-induced cable failure(s) and electrical fault(s) to fire PRA and HRA tasks

General Type of Fire-induced Cable Failure or Electrical Fault	Fire PRA Impact	Fire HRA Impact	Treatment in EPRI/NRC-RES Fire HRA Guidelines
Fire-induced cable failure(s) or electrical fault(s) causes a PRA initiating event (hardware failure), for example, loss-of-coolant accident (LOCA); open steam generator atmospheric steam dump valve; spurious safety injection (SI) signal, which could include spurious containment spray actuation; and interfacing systems LOCA (ISLOCA).	Initiating events are added to the fire PRA model, often with an operator action to prevent or terminate the initiating event. These events can be either local or control room actions.	EOP actions respond to the initiating event. Fire response actions to terminate or prevent the fire-induced cable failure(s) or electrical fault(s).	Identification and definition of EOP actions are discussed in Section 3.2. Termination actions are discussed in further detail in Section 3.3.1.1, and the process for identification and definition is described in Section 3.3.2. Preemptive actions are discussed in further detail in Section 3.3.1.2, and the process for identification and definition is described in Section 3.3.2.
Fire-induced cable failure(s) or electrical fault(s) fails a function or component used in post-initiating event response; for example, fire fails charging pump suction from the volume control tank (VCT) or fire fails valves supplying auxiliary feedwater (AFW) to steam generator (SG).	Failure mode(s) are added to the fire PRA system models, often with an operator action to recover a system failure. These events are typically local actions.	Fire response action.	Fire response actions are discussed in further detail in Section 3.3 and can be quantified using screening (Section 5.1), scoping using MCR tree (Section 5.2.6), or ex-CR tree (Section 5.2.7) or detailed analysis (see Appendices B and C).

Table 2-2
Mapping fire-induced cable failure(s) and electrical fault(s) to fire PRA and HRA tasks (continued)

General Type of Fire-induced Cable Failure or Electrical Fault	Fire PRA Impact	Fire HRA Impact	Treatment in EPRI/NRC-RES Fire HRA Guidelines
Fire-induced cable failure(s) or electrical fault(s) causes an alarm or indication failure that induces the operator to take an action that would make the plant response worse (an error of commission).	Screening for operator errors of commission is conducted, with most (if not all) typically screening out qualitatively. If operator actions are identified and not screened from consideration, an "undesired response to spurious" event would be added to the fire PRA model (with a probability of 1.0). If the fire PRA results show that the HFE is important, an action to recover the undesired response may be modeled.	Undesired response to spurious. Recovery as a fire response action.	Section 3.4 describes the process of identifying and screening undesired responses. If an undesired response survives the screening process, it is included in the fire PRA with a probability of 1.0. Section 3.3.1.3 describes fire response actions for recovering PRA sequences of cutsets. These fire response actions can then be quantified, scoping using MCR tree (Section 5.2.6) or ex-CR tree (Section 5.2.7) or detailed analysis (see Appendices B and C for guidance for these respective approaches).

Table 2-2
Mapping fire-induced cable failure(s) and electrical fault(s) to fire PRA and HRA tasks (continued)

<table>
<tr><th>General Type of Fire-induced Cable Failure or Electrical Fault</th><th>Fire PRA Impact</th><th>Fire HRA Impact</th><th>Treatment in EPRI/NRC-RES Fire HRA Guidelines</th></tr>
<tr><td rowspan="3">Fire-induced cable failure(s) or electrical fault(s) causes alarm(s) and/or indication(s) failure during a scenario that includes operator actions (the case in which the fire-induced cable failure[s] or electrical fault[s] alarm does not induce an operator error of commission).</td><td rowspan="3">Fire impacts, primarily cable failures, affect not only the availability of components for response, but also indications and alarms—with some revealed/active and some unrevealed/passive.</td><td>Part of the context in the scenario definition (in general).</td><td>The scenario context and qualitative analysis are described in Section 4.</td></tr>
<tr><td>SSC.</td><td>Feasibility/reliability issue in which the fire-induced cable failure or electrical fault causes a component to be inoperable (Information Notice 92-18 [10]); see Section 4.3.4.7).</td></tr>
<tr><td>Indications/alarms</td><td>Quantification of the HFE focuses on the reliability of the operator given at least one reliable train of instrumentation. If the fire impact is such that there are spurious operations of non-credited components or instruments, current methods have difficulty quantifying the change in reliability.

Explicit assessment of the impacts of such spurious instrumentation on HEP development is outside the capabilities of existing HRA methods.

Consequently, such events could be flagged for review as potential sources of modeling uncertainty as described in Sections 4.10 and 6.3. For example, if one fire area has action HFE1 and no spurious indications and another area has the same HFE but several distracting spurious indications, the HEP for each area may appear to be the same using today's methods—but the uncertainty associated with each development should be assessed as being different.</td></tr>
</table>

2.6 Technical Bases

The fire HRA methodology has been developed within the framework of, and uses to the extent practicable, HRA methods in widespread use. It is not the intent of this project to develop a new or unique detailed HRA methodology to address fire issues involving PRA, but rather to extend existing methods to address fire conditions when the screening and scoping approaches are not adequate. Although many HRA methods are available, this project focused on two cognitive/execution methods, described next, to perform detailed HRA for fire context. It is also not the objective of this project to research PSFs and screening human error probabilities beyond what is documented in Volume 2, Section 12 of NUREG/CR-6850 [2]. These PSFs are similar to and consistent with those derived by the NRC (defined as *manual actions feasibility criteria*) in NUREG-1852 [12]. Lessons learned from this process can then be applied to other HRA methods on an as-needed basis.

- **EPRI HRA Methodology: Cause-Based Decision Tree (CBDT) [9], HCR/ORE [13] and THERP [14].** Recent industry efforts have focused on a standardized approach using the EPRI CBDT method for the cognitive aspect of HRA, including detection, diagnosis, and decision making. CBDT is complemented by the EPRI human cognitive reliability/operator reliability experiment (HCR/ORE) for modeling cognition of time-sensitive actions. THERP is used to model the execution/manipulation aspect of the HRA. This collective set of CBDT, HCR/ORE, and THERP methods is referred to as *the EPRI HRA approach* in this report.
- **ATHEANA [5, 6].** The NRC's ATHEANA method is suitable for a fire HRA because it offers a structured process for identifying critical aspects of successes and failures associated with abnormal operations. In addition, ATHEANA is not limited to a specific set of PSFs or plant conditions, allowing fire-specific PSFs and contexts to be easily accommodated.

In addition to these two methods, the authors have developed a scoping HRA approach to be used as a simplified quantification approach. This scoping approach was developed by drawing on the principles and concepts embedded in the ATHEANA and EPRI HRA methods as well as other related HRA information (e.g., concepts of feasibility and time margin introduced in NUREG-1852 [12]).

2.7 References

1. National Fire Protection Association (NFPA) Standard 805*, Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants*, 2001 Edition.
2. U.S. Nuclear Regulatory Commission. NUREG/CR-6850, EPRI 1011989, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities.* September 2005.

   Note: When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following as well:

   Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.
3. 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*, The American Society of Mechanical Engineers, New York, NY, February 2009.

4. *Systematic Human Action Reliability Procedure (SHARP) Enhancement Project: SHARP1 Methodology Report*. EPRI, Palo Alto, CA: 1992. TR-101711.
5. U.S. Nuclear Regulatory Commission. NUREG-1880, *ATHEANA User's Guide*, June 2007.
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7. U.S. Nuclear Regulatory Commission. NUREG-1792, *Good Practices for Implementing Human Reliability Analysis*, April 2005.
8. U.S. Nuclear Regulatory Commission. NUREG/IA-0216, *International HRA Empirical Study—Phase 1 Report: Description of Overall Approach and Pilot Phase Results from Comparing HRA Methods to Simulator Data*, Lois, E., Dang, V. N., Forester, J., Broberg, H., Massaiu, S., Hildebrandt, M., Braarud, P. Ø., Parry, G., Julius, J., Boring, R., Männistö, I., & Bye, A. Vol. 1, US Nuclear Regulatory Commission, Washington, DC: 2009.
9. *An Approach to the Analysis of Operator Actions in Probabilistic Risk Assessment*. EPRI, Palo Alto, CA: 1992. TR-100259.
10. U.S. Nuclear Regulatory Commission. NRC Information Notice 92-18, *Potential for Loss of Remote Shutdown Capability During a Control Room Fire*, February 1992.
11. Title 10, Part 50, "Domestic Licensing of Production and Utilization Facilities," of the Code of Federal Regulations (10 CFR Part 50), Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979."
12. U.S. Nuclear Regulatory Commission. NUREG-1852, *Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire*, October 2007.
13. *Operator Reliability Experiments Using Nuclear Power Plant Simulators.* EPRI, Palo Alto, CA: 1990. NP-6937, as supplemented by EPRI TR 100259 [9].
14. U.S. Nuclear Regulatory Commission. NUREG/CR-1278, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications (THERP)*, A. D. Swain and H. E. Guttman, August 1983.

3
IDENTIFICATION AND DEFINITION

3.1 Introduction

The objectives of the identification and definition task are to identify operator actions and associated instrumentation necessary for the successful mitigation of fire scenarios and to define the HFEs at the appropriate level of detail to support qualitative analysis and quantification. These are the first steps in the fire HRA process described in Section 2. The qualitative analysis (presented in Section 4) provides a foundation for all steps in the HRA process; it is therefore recommended that Section 4 be read in conjunction with this section.

It is intended that the identification task be performed early in fire PRA development because the list of associated instrumentation required for operator actions will need to be added to the component selection list in NUREG/CR-6850 [1] Task 2. In addition, the identification of actions can be helpful during the development of the fire-induced risk models in NUREG/CR-6850 Task 5. As the initial risk model is developed, the fire PRA analysts may need to revisit the identification task several times.

HFEs are typically defined in conjunction with HFE identification and, as the fire PRA develops, the definition is refined and revised. The ASME/ANS PRA Standard HLR-HR-F (Chapter 2) [2] outlines the requirements for definition. Consistent with these requirements, the definition activities described in this section are those associated with understanding the PRA boundary conditions for the HFE and the tasks involved in crediting plant staff actions in the PRA.

As in the internal events HRA, operator actions are primarily identified by conducting accident sequence and procedure review. The identification of post-initiating event HFEs for fire HRA is primarily concerned with three types of procedures: emergency operating procedures (EOPs), annunciator/alarm response procedures (ARPs), and fire procedures:

- **EOPs** are required in response to a reactor trip or safety injection. In the United States, EOPs are standardized procedures (by vendor, such as Westinghouse, General Electric, and Combustion Engineering) on which the operators are thoroughly trained. Most internal event HRA actions are identified by reviewing EOPs and associated event trees.
- **ARPs** are those procedures to which the operators are directed in response to an annunciator.
- **Fire procedures** are those procedures (beyond the normal EOPs and/or abnormal operating procedures [AOPs]) that the operators will use in response to a fire. Currently in the United States, there is no standardized fire procedure or procedure format among plants. Fire procedures have historically been developed to meet 10CFR50 Appendix R[5] [3] requirements, but many utilities are transitioning their fire protection program to one based

[5] Within the context of fire PRA, Title 10 Part 50 Appendix R of the Code of Federal Regulations (10CFR50) is commonly referred to as *Appendix R;* this shorthand is used throughout this report.

on the NFPA's risk-informed, performance-based program: NFPA 805 [4]. A plant may have one fire procedure or many, depending on the plant's Appendix R/NFPA 805 program. The level of detail given in the procedures is known to vary widely among plants. Some plants have a specific set of instructions for actions that are required to be performed for a specific fire location; others provide a list of instruments that could be affected by the fire on an area-by-area basis; others are intended for use primarily by the fire brigade; and sometimes control room actions and fire brigade actions are comingled.

The naming of fire procedures can also vary among plants; common names include *fire procedures, fire response procedures, pre-fire plans, fire strategies, serious station fire procedure, main control room abandonment procedures, and site emergency response procedure* (which include a section for fire). NUREG/CR-6850 [1] refers to all of these procedures as *fire emergency procedures* (FEPs). Throughout this report, the term fire procedure will be used to refer to any type of procedure (beyond the normal EOPs/AOPs) that operators use in response to a fire.

For fire HRA, the following three types of post-initiating event operator actions are considered and discussed in this section:

- Internal events operator actions
- Fire response operator actions (including MCR abandonment actions)
- Undesired operator responses to spurious alarms and indications

3.2 Identification and Definition of Operator Actions from Internal Events PRA

A certain set of HFEs is already identified and defined from an internal events PRA. The internal events operator actions associated with these HFEs are actions required in response to a plant initiating event and/or reactor trip, typically directed by the EOPs, ARPs, AOPs, and/or normal operating procedures (NOPs).[6]

Because internal events operator actions have been identified, their HFEs defined, and their HEPs quantified as part of the internal events HRA, it is not necessary to repeat the internal events HRA identification process. All that is required for the fire PRA identification process is to determine which of these HFEs could occur in fire scenarios by considering the fire-induced initiating events and their related fault and event trees from the internal events PRA. This is accomplished by identifying the fire-induced initiating events from NUREG/CR-6850 [1] Task 2 and the HFEs in the logic structures associated with these fire-induced initiating events.

For example, turbine trip is a common fire-induced initiating event, and the internal events PRA often models the response to turbine trip within a "general transient" event tree. All of the HFEs associated with the turbine trip portion of the general transient event tree or related fault trees could therefore occur in fire scenarios. An example of such an HFE is "Operator fails to start auxiliary feedwater" with the implied operator action as "start auxiliary feedwater."

[6] *Normal operating procedures* can also be referred to as *operating procedures*. In this report, the terms *normal operating procedures* and *operating procedures* are assumed to be interchangeable; normal operating procedure (NOP) will be used.

Existing internal events HFEs not associated with any fire-induced initiating events can be screened from further consideration in the fire HRA. For example, steam generator tube rupture (SGTR) is not typically a fire-induced initiating event in a PWR; therefore, fire impact on SGTR HFEs does not need to be considered in the fire PRA.

For fire HRA, there are potentially two subtypes of internal events operator actions: 1) those that are explicitly modeled as basic events in the internal events PRA and 2) those that are proceduralized in the EOPs but are not modeled as basic events in the internal events PRA. The second type of action is identified by the same process as that for actions already included in the internal events PRA. The difference is that when the qualitative analysis stage is reached, the HRA analyst will not have a base analysis from which to work.

To ensure that the identification task is complete, the following steps are all required but not necessarily in the current order. The point at which each of the steps is completed will depend on the development of the fire PRA.

Step 1: Identify operator actions in the internal events PRA. This identification should be straightforward and, in most cases, is a data extraction from the internal events PRA based on basic event name. At this stage, the pre- and post-initiator HFEs are separated. All existing pre-initiator HFEs in the Level 1, internal events PRA model are independent of the initiating event and are therefore independent of a fire initiating event as well. The existing pre-initiator HFEs do not need to be reanalyzed but should be retained as-is in the fire PRA model because their impacts remain relevant to the conditional core damage probability (CCDP) and conditional large early release probability (CLERP).

Step 2: Screen from consideration internal events HFEs that are not associated with fire-induced initiating events. Initiating events relevant to fire PRA are identified in Task 2 of NUREG/CR-6580 [1]. Examples of initiating events not typically included in fire PRA are large loss-of-coolant accidents (LLOCA) and anticipated transient without scram (ATWS) for BWRs and PWRs and SGTR for PWRs. There may be cases in which a single HFE analysis is modeled for several initiating events and the limiting case initiating event is not associated with the fire PRA. In these cases, the HFE should not be screened from consideration but should be reevaluated from first principles to correctly model the fire impacts. For example, the timing of an HFE may be based on the limiting case for large LOCAs and then the same analysis is applied to small and medium LOCAs. In this case, the HFE should be retained for the fire PRA for the small LOCA, and the timing will need to be reevaluated in the qualitative analysis. This information may have been developed previously as part of NUREG/CR-6850 Task 2.

Step 3: Review fire-related fault trees and event trees. ASME/ANS PRA Standard Requirement HR-E1 [2] requires that "*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 and (b) system operation such that an understanding of how the system(s) functions and the human interfaces with the system is obtained.*" This fire HRA guideline has been written with the assumption that the internal events PRA model is up-to-date and meets the requirements of the PRA Standard. However, the fire fault trees and events trees must be reviewed to ensure that internal events actions are still modeled appropriately. This review will identify any actions that were not previously modeled in the internal events PRA but will be needed for the fire PRA. These are proceduralized actions in the EOP and/or AOP/ARP/NOPs that were not considered important for the internal events model because of a low probability of associated component

failure. An example of this type of action is the manual backup of automatic actuation, such as "operator fails to start a pump after automatic actuation failed." Such actions are not always modeled in the internal events PRA because random hardware failures have relatively low failure probabilities for internal events. However, in a fire situation, the hardware could be failed by the fire or its reliability severely degraded, such that these operator actions may become important and could be added to the PRA model.

This step is typically not performed by an HRA analyst in isolation; it requires communication between the PRA fire modeling analyst and the HRA analyst. It is an iterative step that may be revisited as the fire PRA model is developed.

Step 4: Define each internal events HFE for use in fire PRA. The human failures of fire response actions are defined to represent the impact of the human failures at the function, system, train, or component level as appropriate, consistent with requirement HRA-B1 of the ASME/ANS PRA Standard [2]. The definition should start with the collection of information from PRA and engineering analyses, such as the following:

- Accident sequences, the initiating event, and subsequent system and operator action successes and failures leading to the HFE
- Accident sequence–specific procedural guidance (including fire procedures)
- The cues and other indications for detection and evaluation errors
- Accident sequence–specific timing of cues and the time available for successful completion (timing terms defined in Section 4.6.2)
- The high-level tasks required to achieve the goal of the response

The information to be collected to support the detailed definition of the HFE is presented in Section 4.2. The identification and definition process is iterative and is included here as the starting point of the HFE development.

3.3 Fire Response Actions

3.3.1 Types of Fire Response Actions

Fire response operator actions are new post-initiating event operator actions required in response to a fire and are typically directed by the fire procedure(s). They are sometimes called *fire manual actions*, *operator manual actions* (OMAs), or *recovery actions* in other disciplines such as fire protection or NFPA 805 [4] terminology. In this report, they are also referred to as *new MCR* or *ex-control room actions* (i.e., they are fire-specific and were not included as internal events HFEs.) The following sections outline the different types of fire response actions based on their function in the fire PRA. The discussions of each of these types offer examples of HFEs that may be incorporated into a plant's fire PRA and are provided as background information.

3.3.1.1 Fire Response Actions to Mitigate the Expected Consequences of Fire-Damaged Equipment Needed in the Fire PRA

To identify the fire response actions that might mitigate the effects of equipment damaged by fire, each fire area is first reviewed to identify equipment that is potentially damaged by a fire in that compartment or area. This identification is typically accomplished during the performance

of the NUREG/CR-6850 [1] fire modeling tasks during the review of the fire procedure(s). Note that this information may change as the modeling progresses (e.g., information differences related to a complete loss of instrumentation in the first quantification of NUREG/CR-6850 Task 7 versus those for a partial loss of instrumentation in a more detailed quantification of the same area in NUREG/CR-6850 Task 11). Given that fire damage to equipment is identified, the fire procedure(s) applicable to each scenario is reviewed to identify any fire response actions that can be credited for mitigation.

Note that each of these HFEs may require redefinition into multiple HFEs (each representing a subset of the actions originally considered part of the HFE definition). Alternately, some of these HFEs may be consolidated into a single HFE. Such division or consolidation would be decided by the HRA analyst working with the other PRA analysts, taking into account the characteristics of the operator actions being modeled and the level in the PRA model at which the HFE will be placed (e.g., HFE placement at the plant function, system, train, or component level). Examples of fire response HFEs could include the following:

- Operators fail to open a level control valve using a local handwheel after the fire causes remote control to be unavailable
- Operators fail to manually operate a charging pump at the breaker, given that the pumps cannot be controlled from the MCR because fire has damaged control circuits
- Operators fail to close a flow control valve by isolating the air supply
- Operators fail to locally operate a residual heat removal pump when the motor control circuit fails as a result of fire damage
- Operators fail to restore the steam generator level by locally controlling auxiliary feedwater after fire damages the control room indicators
- Operators fail to isolate the power-operated relief valve (PORV) from the control room after it spuriously opens
- Operators fail to locally isolate the PORV after it spuriously opens during the fire and cannot be closed from the control room

It should be noted that in NFPA 805 [4] transition projects, these fire response actions are identified through fire procedure review and are typically modeled (if needed) as recovery actions during the NUREG/CR-6850 Task 14 quantification stages. The reason for this is that the NFPA 805 transition effort uses the fire PRA to provide input to fire procedure modifications.

3.3.1.2 Preemptive Fire Response Actions to Prevent Fire Damage to Equipment (Protect Equipment) Needed in the Fire PRA

Most preemptive fire response HFEs involve failures to deenergize power supplies or disable control systems in order to prevent spurious actuations. When this type of HFE is identified, it should be treated as described in Section 4.9. Examples of such HFEs include the following:

- Operators disable a solid-state protection system
- Operators deenergize a motor control center
- Operators deenergize pressurizer heaters

Preemptive actions are typically performed following either the detection of a fire (e.g., the fire alarm goes off) or the confirmation of a fire locally (e.g., the operator sees flame or significant smoke), depending on the procedure. As such, the action is intended to occur prior to significant fire damage.

The equipment manipulated during these preemptive actions is reviewed against the list of components identified through the NUREG/CR-6850 [1] Task 2, Fire PRA Component Selection. These preemptive actions are then discussed with the fire PRA modeling analyst to evaluate the equipment state change involved and whether it should be reflected in the fire PRA model and included in the component selection list communicated to Task 3, Fire PRA Cable Selection, for cable tracing.

Although these actions are explicitly stated in the fire procedures, the procedures may or may not identify why the actions are to be performed.

At some plants, the fire procedures direct the operators to place the plant in a self-induced station blackout (SISBO) as a preemptive measure to mitigate any spurious actuations. The implementation of SISBO fire procedures involves fault clearance strategies to ensure that a cooling train is protected if portions of a required bus are within the affected zone. According to an ACRS review of fire PRAs conducted by Brookhaven National Laboratory in 1995 [5], these procedures contain a range of fault clearance scenarios—from small single circuits to massive safety bus clearing and power restoration to clearing a limited portion of the bus. Each case involves different procedures for performing a bus clearing. An analysis of SISBO or single-circuit fault clearance strategies should therefore be conducted as part of a safe shutdown analysis to ensure that Appendix R [3] or NFPA 805 [4] safe shutdown system protection requirements are met and that operator manual actions are considered feasible and reliable according to the criteria in NUREG-1852 [6].

Consequently, the fire HRA must make use of input from the fire procedures, Appendix R assumptions, and the experience of operations and training personnel to aid in understanding how the procedures are interpreted and implemented as operator actions and therefore as potential HFEs.

As an example for the case of fault clearance, according to some plant designs, operator actions are required within the fire procedures to manually check or position valves by "resetting" all electrically controlled valves and then manually "realigning" selected valves in a single cooling train. Therefore, modeling these operator actions involves two distinct phases of valve alignment when entering the fire procedures:

1. If the operator is successful in implementing the fire procedure reset steps by deenergizing appropriate electrical buses, all valves and components are placed in the fail-safe position.
2. Then, only those valves and components used in the specified train (outside the fire zone) are restored for active cooling. The operator is then considered to have been successful in implementing the realign steps in the fire procedures by reenergizing the appropriate electrical buses and ensuring that at least one train of cooling is operating.

Operator errors during either the reset or realignment steps are assumed to leave key valves and components modeled in the PRA in the wrong position and should therefore be included as HFEs in the fire PRA model.

3.3.1.3 Fire Response Actions Recovering PRA Sequences or Cutsets

For scenarios in which the internal events operator actions are assumed failed because of fire impacts to the instrumentation or equipment, the HRA analyst may need or wish to credit an additional action. This action could be proceduralized in the fire procedures.

An example of this is an internal events HFE for an operator failing to start a pump. In the internal events model, this HFE is a simple control room action; however, in the fire scenario, the fire fails the control room switch and the HEP evaluates to 1.0. For the fire PRA, the HRA analyst may wish to credit a local action to start the pump. To identify these types of actions, the fire impact on the existing internal events actions needs to be known (and is typically provided through the fire PRA quantification) along with the potential success path to be applied. The latter is often identified as a result of operator interviews. Given that the existing internal events actions applicable to the fire PRA have been identified, the fire impact on them resulting from fire damage to instrumentation is identified during the fire modeling tasks specified in NUREG/CR-6850 [1]. Other impacts such as timing delays also need to be addressed (see Section 4 of this report). As noted previously, the fire impact is first quantified in the fire modeling tasks of Task 7 and later refined in Task 11 of NUREG/CR-6850.

Similarly, the fire response procedures can be written or amended to address recovery of fire-induced or random equipment failures as described in Section 6.1.

3.3.1.4 Main Control Room Abandonment Actions

MCR abandonment actions are a special case, or a subset, of fire response actions. The same identification process applies as that for fire response actions, but the procedure review would be limited to the fire procedures that apply to the decision to abandon the MCR, establishing control outside of the MCR, and performing both command and control functions and actions taken outside of the MCR. Command and control functions are typically performed at a single location such as a remote or alternate shutdown panel. Conversely, actions outside of the MCR may be taken at multiple locations, including the remote shutdown panel, or at one or more local control panels, breakers, or pieces of equipment. Plant parameter monitoring also can be performed at multiple locations (if needed), including from the MCR—if it is habitable and if information that aids diagnosis and decision making is still available there.

Generally, there are two criteria for MCR abandonment, either of which can be used to justify abandoning the MCR: 1) the MCR is uninhabitable (because of smoke, heat, and other fire effects) or 2) the plant cannot be controlled from the MCR (for example, as a result of the fire effects on control cables for the MCR in the cable spreading room). The criteria used in the fire PRA model for MCR abandonment or use of alternate shutdown need to be defined. The decision to abandon the MCR is an area of uncertainty because there may not always be clear and explicit decision criteria for abandonment. When habitability is not an issue, the crew may not completely abandon the MCR even if their ability to control the plant is hindered. In this report, the MCR is considered to be abandoned if command and control are performed outside of the MCR.

In the initial stages of the fire PRA development, the decision for abandonment will be determined by the fire PRA analyst as a simple "yes" (i.e., MCR abandonment is required) or "no" (i.e., MCR abandonment is not required). If the fire PRA determines that the operators will abandon the control room, it is the HRA analyst's task to identify the operator actions required for safe shutdown (based on a review of the MCR abandonment procedure) after the decision to

abandon has been made. If the fire PRA determines that the conditions exist such that the operators will not perform the abandonment procedure to completeness and some operating staff will remain in the control room, the fire PRA analyst will need to define the operator actions required on a scenario-specific basis.

Section 4.8 provides guidance on MCR abandonment modeling.

3.3.1.5 Manual Actuation of Fixed Fire Suppression Systems

NUREG/CR-6850 [1] uses a statistical evaluation of historical events to assign reliability estimates for the fire suppression systems. Suppression is modeled by using non-suppression probability curves. Because the fire suppression probability is addressed with data, it is not necessary for the HRA to model the fire brigade response.

However, the manual actuation of fixed fire suppression systems from the control room during an event is within the scope of the HRA because it is not accounted for in the non-suppression probability curves. These actions are identified by reviewing the fire procedures. Typically, if suppression is required from the control room, the action is proceduralized in the fire procedures on a fire area-by-area basis. In some cases, these actions are proceduralized in the fire brigade response procedures.

3.3.2 Fire Response Action Identification and Definition

The fire response operator actions are identified by a systematic review of the fire procedure(s) to identify the fire response actions required in the fire PRA. To understand which fire response actions are required in the fire PRA, it is necessary to first understand the fire scenarios, which may require modeling of the fire impacts on equipment and instrumentation in the fire PRA. However, if the fire PRA modeling has not yet advanced to this stage, **all** procedural fire response actions could be identified, and some can be excluded from further consideration if it is later determined that they are not required in the fire PRA. Because the fire HRA is being developed in conjunction with the fire PRA and may therefore differ with each fire PRA project, four approaches are presented for identification.

Approach 1: Identify specific fire response actions required for mitigation given the fire impacts on equipment and instrumentation. For this approach, ideally, the fire PRA has developed past Task 5 (Risk Model Development) of NUREG/CR-6850 [1]. The HRA analyst and fire PRA analyst will work together to review the fire scenarios in conjunction with the fire procedures, EOPs, fault trees, and event trees. To identify the operator actions in this approach, the fire PRA analyst will need to create a timeline for the fire sequence of events with enough detail to allow the HRA analyst to map the expected operator action as directed in the fire procedures to the specific fire sequence. This may also require operator interviews to confirm the expected plant response for each fire scenario.

Approach 2: Identify all procedural fire response actions and incorporate only those that are required for mitigation when the fire impacts on equipment and instrumentation become known. In this approach, the HRA analyst can identify the fire response actions without significant input from the fire PRA analyst. The fire procedure review will simply document all possible actions listed in the fire procedures. As part of this approach, the HRA analyst would map the identified fire response actions to internal events actions, if applicable. An example of this approach is shown in Table 3-1.

Table 3-1
Examples of fire response HFEs using identification Approach 2

Fire Response Basic Event Identifier	Related Basic Event Identifier in PRA	Equipment	Fire Response Basic Event Description
ACP-OPS-ISO-1F1A	None	4160-V Bus 1F	Operators fail to isolate 4160-V Bus 1F from Bus 1A.
ACP-OPS-ISO-1FDG1	EAC-OPS-FO-DG1 – Operators fail to operate Diesel Generator 1 (DG1)	DG1	Operators fail to align DG1 to 4160-V Bus 1F by isolating and operating DG1 and Breaker EG1 according to Section 10 of Procedure 5.4.30.1.
CS-OPS-OC-MO15	LCS-OPS-FO-MO15 – Operators fail to align condensate storage tank (CST) to pump suction from the control room	CS-MO-12A	Operators fail to open CS-MO-15 using contactor or handwheel according to Section 11 of Procedure 5.4.30.1.
HPCI-OPS-OC-CD	RHR-OPS-FO-RHRA – Operators fail to cool down using high pressure coolant injection (HPCI) for small LOCA	HPCI/residual heat removal (RHR)	Operators fail to cool down using HPCI and establish RHR according to Section 9 of Procedure 5.4.30.1.
FZ50-OPS-SUPRESS	None	Fire suppression system FZ AA-55	Operators fail to activate suppression system for AA-55 from control room.
AFW-OPS-XTIE-FIRE	AFW-OPS-XTIE – Operators fail to cross-tie auxiliary feedwater (AFW) according to AOPs	AFW FM-124	Operators fail to cross-tie AFW according to the MCR abandonment procedure

This approach is resource intensive for the HRA analyst but does provide clear documentation of the procedure review in order to meet PRA Standard Requirements HR-E1 and HR-E2 [2]. This approach also provides the fire PRA analyst with all possible actions that can be credited, allowing the fire PRA analyst to implement these actions on an as-needed basis.

Approach 3: An iterative approach combining the first two approaches. Because the fire HRA task is typically not performed independently of the fire PRA, a hybrid approach of the first two approaches may be performed. The hybrid approach would be plant- and model-specific. For example, as the risk model is being developed, the HRA analyst could review the fire procedures to identify MCR abandonment actions with the assumption that MCR abandonment is required. After the fire PRA has developed the MCR abandonment scenarios, the HRA analyst can define the actions for the specific fire sequence. If the fire modeling has progressed to a stage at which specific locations are determined to be risk-significant, the HRA analyst could take these areas and review only sections of the fire procedures specific to the risk-significant areas.

Approach 4: Review the fire procedures to identify the equipment state changes produced by the operator actions directed by the procedures. Another approach is to review the fire procedures to identify the equipment state changes produced by the operator actions directed by the procedures, such as in the examples in Table 3-2.

Table 3-2
Examples of fire response HFEs using identification Approach 4

Equipment	Initial Position	Desired Position	Comments
15123BKR	Open	Open	For fires in Zone A, Fire Procedure (FP) -1 Attachment A and FP-2 Attachment B direct operators to open the knife switch of 15123BKR.
VLV-15	Closed	Open	For fires in Zone A, FP-1 directs operators to reduce charging flow by closing this valve or pulling the fuse for VLV-15 in Cabinet X. For large fires in Zone B, FP-3 directs operators to pull the fuse for VLV-15 in Cabinet X.

In the first example in Table 3-2, the desired position for the breaker is open, and the fire procedure action directs the operator to open the breaker. Therefore, if fire causes spurious closure of the breaker, this would be a fire response operator action that could be modeled either up front or as a recovery action if the quantification identifies the cutsets in which this appears as risk-significant.

In the second example, the desired position for the valve is open, and the fire procedure action directs the operator to close the valve. This operator action can be considered included in the fire-specific basic event of “valve fails to open due to fire” quantified with a 1.0 for fires in the appropriate zone.

Modeling decisions such as these are made jointly between the fire HRA and fire PRA modeling tasks.

3.3.2.1 Definition of Fire Response Actions

The human failures of fire response actions are defined to represent the impact of the human failures at the function, system, train, or component level as appropriate. The definition should start with the collection of information from PRA and engineering analyses, such as the following:

- Accident sequences, the initiating event, and subsequent system and operator action successes and failures leading to the HFE
- Accident sequence–specific procedural guidance (such as fire procedures)
- The cues and other indications for detection and evaluation errors
- Accident sequence–specific timing of cues and the time available for successful completion (timing terms defined in Section 4.6.2)
- The high-level tasks required to achieve the goal of the response

Further discussion on how and what to consider in the detailed definition of the HFE is presented in Section 4.2. The identification and definition process is iterative and is included here as the starting point of the HFE development.

3.3.2.2 Unique Issues for the Identification and Definition of SISBO Human Failure Events

The following are some unique issues that need to be considered in identifying and defining HFEs for the fault clearance scenario through the review of pre-emptive operator actions such as SISBO fire procedures:

- The HRA review of the SISBO procedure may need to identify groups of steps that the operators use to achieve each safety function in controlling the plant response to a fire as a function of the fire zone as well as other performance shaping factors.
- If unexpected conditions occur during the application of fire procedures, the operators can insert contingency actions—some of which are preplanned for fires, some are in the emergency procedures, and others are from general training. Only equipment and hardware with verified cable routing outside the fire zone are used for such contingency actions.
- As is the case for plants that do not employ the SISBO approach, SISBO fire procedures do not provide explicit guidance for responding to events such as LOCAs that may be relevant in a PRA. The PRA scenarios will need to be reviewed in conjunction with the fire procedures in order to understand the potential for competing tasks. In many cases, the operator's response to SISBO fire procedures will be modeled at the event tree level as opposed to the fault tree level.

3.4 Identification and Definition of HFEs Corresponding to Undesired Operator Responses to Spurious Instruments and Alarms

For fire HRA, an *undesired action* is defined as a well-intentioned operator action that is inappropriate for a specific context and that unintentionally aggravates the scenario. Undesired responses consist primarily of shutting down or changing the state of mitigating equipment in a way that increases the need for safe shutdown systems, structures, and components (SSCs). The key criterion in identifying undesired operator actions is that the action leads to a worsened plant state (e.g., turning a transient initiating event into a consequential LOCA). If an operator responds to a spurious indication and the action is judged not to impact the CCDP or CLERP, it does not need to be considered further.

In fire events, spurious indications occur when electrical cables routed through a zone in which the fire is postulated are shorted, grounded, or opened as the cable insulation is burned. These instrument wires feed alarms and control indications that act as cues for operator actions. Therefore, an undesired action can be triggered through a false cue that tells the operator to take an action that is potentially detrimental to safe shutdown. For example, an action is classified as *undesirable* if the operators conclude, from false cues, that the safety injection (SI) termination criteria are met and then shut down SI when it is inappropriate to do so. In addition, if the instrument fails to operate because of fire damage and the cue is not provided to the operator, an action could fail to be taken (i.e., an error of omission could occur) that could also be detrimental to safe shutdown.

This section describes the process for identifying and screening fire-induced cable failure(s) or electrical fault(s) that causes a spurious alarm or indication failure that potentially induces the operator to take an action that would make the plant response worse (i.e., an error of commission). Section 2.5 provides an overview of the different types of fire-induced cable failures and the location of the associated guidance in this report.

The undesired operator actions are identified within the context of the accident progression. When the EOPs are implemented, the operators follow them and remain in the EOP network until the plant has reached a safe, stable state, at which time normal procedures can be implemented again. During the initial EOP response, the operators are trained to respond only to indications, annunciators, or alarms that are referenced in the EOPs or that are pertinent to the scenario. In practice, when the accident diagnosis is complete, the required equipment status is verified, and the plant is stabilized, the operators would resume normal protocol for monitoring the control room and attending to annunciators or alarms. In a fire scenario, the operators would also implement the fire procedures, either in parallel with the EOPs or by suspending the EOPs while the fire procedure(s) are performed, depending on plant-specific procedural guidance and training.

To reasonably bound the number of modeled, undesired operator actions resulting from spurious indications, it is recommended that human performance–based criteria be developed to be applied consistently in the identification process. Such criteria should be based on the plant-specific factors that govern operator cognitive response to indications such as the following:

- Cue parameter(s)
- Cue (procedural) hierarchy
- Cue verification
- Degree of redundancy for a given parameter

Each of these factors is briefly discussed next.

Cue Parameters

The cue for an operator cognitive response may consist of a single parameter or multiple parameters. For example, low lubrication oil pressure for a pump is a single parameter that would actuate an alarm that would require the operator to trip the pump to protect the bearings. As an example of multiple parameters, the cue for implementing the functional restoration procedure for loss of secondary cooling on a PWR is based on multiple parameters: low steam generator feed flow and low steam generator narrow range level.

For operators to be misled by a single parameter cue, a spurious indication on the single parameter would be sufficient; for a multiple parameter cue, multiple spurious indications on different parameters would be required. It would seem that multiple spurious indications on different parameters would be less likely to mislead the operator than a spurious indication on a single parameter, but the relative likelihood would depend on the fire impact on instrumentation in a specific scenario. To meet Capability Category II of the fire PRA Standard, only single-instrument failures need to be considered.

It should be noted that the evaluation of potential multiple spurious operation (MSO) of SSCs on the success path required for hot shutdown and those important to safe shutdown consistent with the ASME/ANS PRA Standard [2] High-Level Requirement ES-B is conducted as part of the fire PRA Task 2 on Component Selection. For those assessments, an expert panel is convened to

evaluate a generic set of MSOs according to NEI 00-01 [7] (as referenced by Regulatory Guide 1.189 [8] and NEI 04-02 [9]) for their plant-specific relevance and modeling strategy for the fire PRA.

However, according to PRA Standard Requirement ES-C2, the fire PRA Component Selection Task 2 is also required to identify instrumentation relevant to operator actions modeled in the fire PRA, particularly when the spurious operation of the instruments could result in an undesired operator action. This is discussed in detail in Section 2.5.5.2 of NUREG/CR-6850 [1]. For this reason, it is important that the fire HRA task work closely with the component selection task to ensure that the evaluations are consistent and complete.

Cue (Procedural) Hierarchy

Following a reactor trip or safety injection, operator response is governed by procedures, starting with entry into the EOPs. During the initial EOP response, the crew basically focuses on plant parameters and alarms that are called out in the EOPs. Other annunciators and alarms may be ignored until the plant is stabilized unless the cue is pertinent to the scenario. In the EOPs, certain cues are required to be monitored continuously; they may be known as continuous action statements, floating steps, and/or foldout page instruction(s), depending on the vendor. The operators also may have some cue-specific indication preferences based on training, procedures, ease of use, and reliability. When a continuously monitored cue occurs, the operators may be required to suspend what they are doing and perform the instruction(s) associated with the cue. Cues may be further prioritized. For example, Westinghouse EOP cues are prioritized by: 1) safety function and 2) severity of challenge to safety function in the critical safety function status trees (CSFSTs) that are monitored from a certain point in the EOPs. Although there may be plant-specific deviations, operators generally prioritize the cues as follows:

1. Cues that are continuously monitored
2. Cues that are called out in the EOPs as checks but are not continuously monitored
3. Cues that are not called out in the EOPs but that may be pertinent to the scenario
4. Cues that are not called out in the EOPs and that are not pertinent to the scenario

Cue Verification

Certain cues may require an immediate response, while other cues may require verification prior to action. For example, a typical ARP may require the operators to verify the validity of the cue by comparing it with other indications or by performing a local inspection.

Operators are more likely to be misled by a spurious indication(s) of a cue that requires an immediate response than a cue that is required to be verified first.

Degree of Redundancy for a Given Parameter

Most plant parameters have redundant instrumentation channels and indications. For example, each steam generator level indicator may have three or four redundant instrumentation channels. The operators expect all of the redundant channels to provide the same indication of the parameter. Should one of the redundant channels deviate significantly from the other channels, the operators are likely to suspect that an instrumentation failure has occurred. The operators

would enter the AOP for instrumentation failure, which would require the suspect instrumentation channel to be placed in the tripped position. However, if additional indications deviate, it may become progressively more difficult to determine which are correct and which are not.

Operators are not likely to be misled by a spurious indication on one of several redundant instrumentation channels, but they may be misled by multiple spurious indications on redundant channels.

3.4.1 Process for Identifying and Defining HFEs That Result in Undesired Operator Response

Based on the previous discussion, a recommended process for identifying and defining HFEs that represent inappropriate responses to spurious indications has been developed and is described next. As part of the identification process, the HRA analyst may find it useful to perform preliminary operator interviews to develop an understanding of how the plant-specific crew anticipates responding to spurious indication.

Step 1: Review ARPs for undesired operator response actions. The ARPs are to be systematically reviewed to identify potential undesired operator actions that can result from an annunciator or alarm. ARPs to review are those that involved equipment or systems modeled in the fire PRA. Although operators may not respond to annunciators or alarms that are not referenced in the EOPs during their initial implementation, the annunciators or alarms will remain “in alarm” and will eventually be responded to. At most U.S. nuclear power plants, crews are trained to rely on multiple and diverse indications before taking action. The following assumptions can be made to reasonably bound the number of undesired operator actions in accordance with Capability Category II of the fire PRA Standard:

- Actions that require multiple spurious indications on different parameters can be screened from consideration.
- Actions that require multiple spurious indications on redundant channels can be screened from consideration.
- Actions that include a proceduralized verification step can be screened from consideration if the verification will be effective given the fire scenario.

Step 2: Review EOPs for undesired operator response actions. The EOPs are to be systematically reviewed to identify all steps in which an undesired operator action can result. EOPs to review are those that the operators are expected to perform for all fire-induced initiating event scenarios in the fire PRA model. Each step in the procedure that contains some decision logic with reference to a plant parameter is to be considered for the potential to cause an undesired operator action if the indication associated with the parameter is spurious. The instrumentation associated with the plant parameter could be identified in the EOPs, the EOP background documentation, instrumentation and control diagrams, and/or control room panel layout drawings or pictures.

The same assumptions used in the ARP review for screening undesired operator actions also can be applied to the EOP review. EOP actions are typically based on parameter indications in the MCR with redundant indication channels. In addition, the symptom-based EOPs are designed to provide additional confirmation after significant decision points to allow the operating crew to

correct any misdiagnoses that may have occurred. Experience gained in fire PRAs to date indicates that detailed analysis of the EOPs to identify potential undesired operator responses in response to a single instrument failure (as required to meet Capability Category II of Supporting Requirements HRA-A3 and HRA-B4 [2]) will identify few, if any, undesired operator actions.

Step 3: Define HFEs. The undesired operator response actions should be defined to represent the impact of the human failures at the function, system, train, or component level as appropriate. There are three approaches to modeling these events:

- Approach #1: Model a single basic event representing the operator making the initial error (prompted by the spurious indication) combined with an implicit recovery action.
- Approach #2: Model two basic events, one representing the operator making the initial error (prompted by the spurious indication) and the second modeling an explicit recovery action of the first event. In this approach, the first event should be assigned an HEP of 1.0 unless justification can be provided for a lower value, and the recovery event should be modeled following the fire HRA process defined in Sections 4 through 6 of this report.
- Approach #3: Model the spurious instrument operation and equipment change of state resulting from the undesired operator action as fire-related component failure basic events, and address the recovery action as an HFE either up front or when the cutset(s) in which the equipment basic event appears surfaces as risk-significant. For example, the "instrument fails spuriously due to fire" basic event is one input to an OR gate for an event "flow from pumps to condenser A stopped or reduced." The pump recovery action can then be addressed as an HFE.

Similar to the internal events actions, fire response action definition should start with the collection of information from PRA and engineering analyses, such as the following:

- Accident sequences, the initiating event, and subsequent system and operator action successes and failures leading to the HFE
- Accident sequence–specific procedural guidance (such as fire procedures)
- The cues and other indications for detection and evaluation errors
- Accident sequence–specific timing of cues, and the time window for successful completion
- The time available for action
- The high-level tasks required to achieve the goal of the response

To ensure that the identification task is complete, the three steps described previously are all required but not necessarily in the order presented. The point at which each step is completed will depend on the development of the fire PRA. Further discussion on how and what to consider in the detailed definition of the HFE is presented in Section 4.2. The identification and definition process is iterative and is included here as the starting point of the HFE development.

3.4.2 Examples of Operator Actions That Result in Undesired Response

Examples of operator actions listed in the EOPs that could result in undesired responses are shown in Table 3-3.

Table 3-3
Examples of operator actions in EOPs that could result in undesired responses

Procedure	Parameter	Spurious Indication	MCR Instrumentation	Undesired Action	Consequence if Operators Respond to Spurious Indication
E-0 Step 4 RNO	Containment (CNMT) pressure	>5 psig (0.03 MPa)	PI LM100A PI LM100B PI LM100C PI LM100D PR 1LM 100A	Actuate SI	Fill pressurizer, challenge PORVs, consequential LOCA
E-0 Step 25	Reactor coolant system (RCS) pressure	>275 psig (1.90 MPa)	PI RCS 402 PI RCS 403	Stop LHSI pumps	Loss of core cooling

In the first example, the operators are required to check SI status and to actuate SI if required in E-0 Step 4. If SI is not required in the scenario but the operators see a false high containment pressure, they will actuate SI. The instrumentation associated with containment pressure is shown in the *MCR Instrumentation* column; there are four redundant pressure indications (PI) and a diverse pressure recorder (PR) device.

In the second example, the operators are required to stop the low head safety injection (LHSI) pumps if reactor coolant system (RCS) pressure is higher than 275 psig (1.90 MPa) in E-0 Step 25. This step is also a continuous action step; that is, when the operators reach Step 25, they will begin to monitor the RCS pressure to stop the LHSI pumps, if required.

To meet Category II of the fire section of the PRA Standard, both examples shown in Table 3-3 could be screened from further consideration. The first example refers to a parameter for which there are both diverse and redundant indications; the second contains redundant indications.

Examples of operator actions based on spurious annunciators that could result in undesired responses are listed in Table 3-4.

Table 3-4
Examples of operator actions based on spurious annunciators that could result in undesired 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, reducing ESW probability 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 temperature on many components but can be restarted.

Table 3-4
Examples of operator actions based on spurious annunciators that could result in undesired responses (continued)

Spurious Annunciator	Undesired Action	Consequence
East RHR pump suction valves not fully open	Immediately open 1-IMO-310, east RHR pump suction, or 1-ICM-305.	Depending on the scenario (size of LOCA), could lead to cavitation of the pump. Loss of pump in recirculation mode.
RHR pumps motor instant trip	Place pump control switch in lockout.	Delayed start of RHR if not on, or halts RHR if on. Impacts CCDP. Can be manually started.

Based on the information identified, all four examples in Table 3-4 could be retained for further analysis and incorporated into the fire PRA because only one instrument (annunciator) has been identified as leading to an undesired consequence. The HRA analyst may wish to further investigate other cues and indications that the operators would review before responding to this alarm and then show that the annunciators as well as indications would be used for diagnosis and screened from further consideration.

These operator actions would be included in the fire PRA with an HEP of 1.0. As a result, the fire PRA logic would need to reflect, for example, the unavailability of the equipment taken out of service by the operator because of undesired response to spurious indications.

3.5 Initial Assessment of Feasibility

After the operator action has been identified and the HFE defined, the HRA analyst needs to initially determine whether the operator action is feasible. The feasibility check ensures that the fire PRA is not crediting an operator action that may not be possible. During the identification and definition stage, the initial feasibility assessment is conducted primarily based on information obtained during the HFE definition and supplemented by any additional information that may be known about the particular action or PRA scenario. Feasibility should be treated as a continuous action step and reviewed periodically as the HFE is further developed and refined. Section 4.3 provides a complete discussion on the assessment of feasibility.

If an operator action is not feasible, the HEP should be set to 1.0. After the preliminary results have been incorporated into the model, additional resources can be used to reassess actions that were previously considered not feasible. There will always be cases in which, with enough information, the HRA analyst could make an argument that an action is feasible even though the initial information suggests that the action will be extremely difficult or vice versa.

The following questions represent feasibility information that may be known at this stage of the analysis:

- **Is there sufficient time to complete the action?** The analyst should ensure that there is sufficient time available to complete the action. If there is not, the HEP should be set to 1.0. Both the total time required to accomplish the action and the time available should be determined. The total time required for the action consists of the amount of time required for diagnosis and the amount of time required for execution (including transit time). The total

time required must not exceed the total time available to complete the action. The total time available can be an estimate based on thermal-hydraulic calculations or engineering judgment early in the overall NUREG/CR-6850 [1] quantification tasks.

- **Are there sufficient cues available for diagnosis?** The analyst should ensure that there are sufficient cues for diagnosis. If all of the cues for diagnosis are impacted by the fire such that the action cannot be performed, the action is considered not feasible.
- **Is the location where the action is to be accomplished accessible?** If any of the required critical tasks is in the same location as the fire or it is known that the operators will not be able to reach the location(s) because of the fire, the HEP should be set to 1.0.
- **Is there enough staff available to complete the action?** If there are not enough crew members available to complete the action (i.e., the number of people required for each task exceeds the number of crew available), the HEP should be set to 1.0.
- **Has the fire impacted equipment such that required critical tasks cannot be performed?** This item includes instrumentation and/or alarms and component operability considerations. There must be at least one channel of instrumentation and/or alarms for cue(s) for an operator action to be feasible. Similarly, the components manipulated during the operator response must be free of fire damage. If the fire has damaged the equipment such that it will not function (even if the operator takes the appropriate action), the HEP should be set to 1.0. For example, if an auxiliary feedwater pump is physically damaged by fire, the operator action to start the pump locally would not be feasible.

In the identification and definition stage, the HFE narrative and information about each performance shaping factor (PSF) are likely not yet known. As this information becomes available, the feasibility step should be reassessed as described in Section 4.3.4.

3.6 Incorporating Fire HRA into Fire PRA

After HFEs have been identified and defined, they can be incorporated into the PRA model. Task 5, Step 1.3 of NUREG/CR 6850 [1] provides the following guidance on incorporating HFEs into the fire PRA model:

> During the early phases of the model development process, the model configuration setting function of the quantification tool can be used to temporarily assign a value of 1.0 or TRUE for surrogate events in the model. Surrogate events are typically existing human failure events in the Internal Events logic model. New fire-specific human failure events may have to be added to the logic models based on actions specified in the fire procedures. During the final stages of the model development process, unscreened fire-induced human failure events will be explicitly incorporated into the logic models. The fire-induced human failure basic events will be conditional on the appropriate fires.

Refinements to these HFEs are likely to occur as other fire PRA tasks are performed. In deciding which actions to credit initially, the analyst may choose to perform some sensitivity analyses to determine whether such actions need to be credited in the fire PRA by using the current internal events PRA (or during the development of the fire PRA model) or by setting the HEPs to a value provided by the screening, scoping, or detailed assessment methods.

HRA analysts should use existing guidance on the interface between the HRA and PRA tasks, including the way in which HFEs are modeled and placed into PRA logic models. For example, Section 5.2.3.1 of NUREG-1792 [10] recommends that HFEs "be placed in proximity … to the component, train, system, and function affected by the human failure event." In addition, Section 3.9.2 of NUREG-1624 [11] recommends that altering the PRA logic model to accommodate HFEs, especially errors of commission (such as undesired responses to spurious indications) may be needed, particularly if the HFEs occur only in very specific contexts.

3.7 References

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

   Note: When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following as well:

   Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.
2. 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*, The American Society of Mechanical Engineers, New York, NY, February 2009.
3. Title 10, Part 50, "Domestic Licensing of Production and Utilization Facilities," of the Code of Federal Regulations (10 CFR Part 50), Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979."
4. National Fire Protection Association (NFPA) Standard 805, *Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants*, 2001 Edition.
5. U.S. Nuclear Regulatory Commission. NUREG-1125, Volume 18, *A Compilation of Reports of The Advisory Committee on Reactor Safeguards - 1996 Annual*, "Review of Recent Fire Probabilistic Risk Assessment Reports by Brookhaven National Laboratory and Certain Fire Barrier Issues, March 15, 1996", April 1997.
6. U.S. Nuclear Regulatory Commission. NUREG-1852, *Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire*, October 2007.
7. NEI-00-01, Revision 2, *Guidance for Post-Fire Safe Shutdown Circuit Analysis*. Nuclear Energy Institute, Washington, D.C.: May 2009.
8. U.S. Nuclear Regulatory Commission. Regulatory Guide 1.189, *Fire Protection for Nuclear Power Plants*, October 2009.
9. NEI-04-02, Revision 2, *Guidance for Implementing a Risk-Informed Performance-Based Fire Protection Program Under 10 CFR 50.48(c)*. Nuclear Energy Institute, Washington, D.C.: April 2008.
10. U.S. Nuclear Regulatory Commission. NUREG-1792, *Good Practices for Implementing Human Reliability Analysis (HRA)*, April 2005.
11. U.S. Nuclear Regulatory Commission. NUREG-1624, Rev. 1, *Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (ATHEANA)*, May 2000.

4 QUALITATIVE ANALYSIS

4.1 Introduction

Qualitative analysis is an essential part of an HRA although not always explicitly identified as a separate step in the HRA process. The objectives of the qualitative analysis are to understand the modeled PRA context for the HFE, understand the actual "as-built, as-operated" response of the operators and plant, and translate this information into factors, data, and elements used in the quantification of human error probabilities. A sound qualitative analysis allows the HRA to provide feedback to the plant on the factors contributing to the success of an operator action and those contributing to the failure of an operator action. Because the qualitative analysis provides a foundation for **all** steps in the HRA process, it is recommended that Section 4 be read early in the HRA process, and be revisited as needed throughout the HRA.

As an example, the objective data collected at the start of the definition of existing internal events HFEs in Section 3.2 must be reviewed and revised to understand the impacts of the modeled fire. Each of the assumptions and inputs used in the internal events HFE analysis must be systematically considered and evaluated for potential impact, including the following:

- Fire impact on instrumentation and indications credited for detection and diagnosis as well as the quality of the indications following a fire
- Fire impact on the timing of cues, response, execution, and time available
- Fire impact on success criteria, such as a system requiring local, manual action after a fire
- Fire impact on procedural usage, such as whether the fire procedures supplement or supersede the EOPs
- Fire impact on manpower resources, which may limit the operator's responses
- Fire impact on local actions, for example, accessibility, atmosphere, and lighting

The results of qualitative analysis are needed for two of the key HRA process steps: the identification and definition of HFEs and the development of human error probabilities for HFEs. The qualitative analysis can also be a product itself, forming the basis for the HFEs that plant personnel can use to improve plant response. In addition, qualitative analysis can be an input into the selection of an HRA quantification method that is appropriate for specific HFEs.

In the SHARP1 process [1], qualitative analysis tasks are embedded in the discussion of the HFE identification and definition step (Stage 1 of SHARP1). Specific HRA quantification methods (such as those used in the EPRI HRA approach [2]) explicitly identify the required input information needed to perform quantification and implicitly define the information that needs to be collected or developed as part of qualitative analysis. In ATHEANA [3,4], qualitative analysis tasks are explicitly described in certain steps (e.g., identify potential vulnerabilities) and implied in others (e.g., identify candidate HFEs).

Because it supports almost all other HRA tasks, qualitative analysis is iterative—just as HRA is iterative. Information collection and evaluation starts with project initiation and continues until the final HEPs are documented. Initially, the HRA analyst may be collecting and processing basic information (e.g., EOPs) to gain enough information to appropriately identify and define HFEs. Later, the HRA analyst is likely to be collecting and processing information on the way in which EOPs are used by the operating crew in specific PRA scenarios (e.g., through interviews of operators and operator trainers). Other sources of information (e.g., the timing of plant behavior as predicted by thermal-hydraulic calculations) may be refined during the PRA study, changing the time available for certain operator actions in particular PRA scenarios and, as a result, changing HRA quantification inputs or indicating the need to define new HFE cases.

This section includes an overview of the issues to be considered, qualitatively, in performing a fire HRA. It is based on guidance found in the combined PRA Standard [5], SHARP1 [1], ATHEANA [3, 4], and NUREG-1792 [6]. It is recommended that this section be reviewed prior to performing any of the fire HRA tasks. The information in this section will provide a useful understanding of the issues associated with the fire context, thereby supporting HFE identification and definition, and forming the basis for the specific inputs required for HFE quantification. For the most part, specific guidance on addressing these fire context issues during HRA quantification are provided in the relevant sections. However, the information in this section establishes a knowledge base that is important for the thoughtful application of the quantification approaches. In addition, because the fire context is the most important driver in deciding which information needs to be collected and assessed, it is not possible to develop a generic, one-to-one relationship between specific qualitative analysis activities and specific fire HRA quantification methods (e.g., the scoping approach versus one of the detailed fire HRA approaches).

This section consists of eleven subsections that address the following:

- Section 4.2 discusses the types of information typically collected to support the HRA development (and their sources).
- Section 4.3 describes what a feasibility assessment is and how it can be performed.
- Section 4.4 briefly discusses the way in which qualitative inputs aid in the selection of an appropriate HRA quantification method.
- Section 4.5 provides guidance on developing an HFE narrative (as a qualitative input to HRA quantification or as a product in and of itself).
- Section 4.6 provides a general discussion of several PSFs that are typically addressed in HRA and some that are of specific concern for fire contexts.
- Section 4.7 discusses the way in which a review of relevant operating experience can be used as an input to fire HRA.
- Sections 4.8 and 4.9 address specific qualitative analysis associated with MCR abandonment HFEs and preemptive operator actions such as those called out in SISBO procedures.
- Section 4.10 discusses the aspects of qualitative analysis associated with operator response to fire-induced spurious operation of instrumentation and equipment.
- Section 4.11 explains how a review of plant-specific operations can be used as an input to fire HRA.

4.2 Information Collection

Qualitative analysis starts with a collection and review of information supporting the development of the modeled HFEs. This information is likely to be collected as part of the identification and definition task described in Section 3. If not, the data are collected at the start of the HRA quantification.

The information comes from three general sources: the PRA, the plant, and the existing HRA. The following types of data are useful to collect for each source:

- PRA information needed to understand the modeled context for each HFE:
  - PRA model consisting of the fire-induced initiating events, event trees for plant response, fault trees for system response, and data and results (such as for accident sequences and important contributors)
  - Success criteria analyses providing the basis for the accident progression modeling and times to component damage such as room or system heat-up calculations
  - Timing information such as from thermal-hydraulic calculations
  - Other deterministic analyses such as circuit failure analyses and fire growth models
- Plant information needed to understand the actual "as-built, as-operated" plant response:
  - Procedures including EOPs, abnormal operating procedures, and fire procedures
  - Alarms and instrumentation associated with fire operator response
  - System descriptions for systems credited in the fire PRA, following NUREG/CR-6850 [7] Task 2 component selection
  - Operator training information such as the types and frequency of training associated with the fire initiating events
  - Location and plant layout information
  - Plant staffing and roles following a fire
  - Fire protection evaluations of the feasibility of operator manual actions
- HRA-specific information needed to understand existing HRA methods and data sources:
  - HRA from the internal events PRA providing qualitative and quantitative data and analyses
  - Interview notes from discussions and talk-throughs with operators and/or operator trainers
  - Simulator observations and walk-through data

4.3 Feasibility Assessment

Before an analyst can quantify the reliability of an operator action, the analyst must know whether the action can succeed. The feasibility analysis in the fire HRA assesses whether the operator action can be accomplished in the context associated with the response to a fire-induced initiating event. The dictionary definition of a *feasible* action is one that is *capable of being done or carried out*.

The use of the term *feasibility* as applied to HRA appears to have its genesis in the consideration of fire ex-control room manual operator actions submitted by nuclear plant licensees as exemption requests from the deterministic requirements of 10 CFR Part 50, Appendix R [8] as a way to achieve and maintain hot shutdown conditions during and after fire events.

The feasibility of operator actions is discussed in NUREG/CR-6850 [7] only from the standpoint of recovery actions for fires in the MCR and the evaluation of crediting the operator use of firefighting water for core injection, heat removal, or secondary heat removal. However, the feasibility assessment actually correlates with several NUREG/CR-6850 tasks as discussed in Subsection 4.3.1.

NRC Inspection Procedure (IP) 71111.05, Fire Protection (Triennial) [9] requires that every three years, an inspection team select three to five risk-significant fire areas/zones and conduct a risk-informed inspection of selected aspects of the licensee's fire protection program, including the "feasible and reliable manual actions to achieve safe shutdown."

The subsequently issued NUREG-1852 [10], *Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire*, provides guidance on assessing the feasibility of local fire OMAs performed outside the MCR—either upon detecting a fire to protect critical safety equipment that might be failed or spuriously affected and rendered unavailable by the fire, or to locally and manually align critical safety equipment to perform its function when needed. NUREG-1852 defines a feasible OMA as one "that is analyzed and demonstrated as being able to be performed within an available time so as to avoid a defined undesirable outcome."

It should be noted that specific requirements for the feasibility assessment of recovery actions in NFPA 805 [11] transition projects (beyond those identified in this section) are discussed in FAQ-07-0030 [12] and include field demonstrations and periodic drills that simulate the conditions to the extent practical. The term *recovery action* in NFPA 805 transition projects refers to OMAs taken outside the MCR or "primary control station" (such as a remote shutdown panel), as defined in NEI 04-02 [13].

In the context of fire HRA, *feasibility assessment* is the qualitative consideration of whether the operator action is go/no-go, considering the major performance influencing factors discussed next. If the action is not feasible, an HEP of 1.0 is assigned, or the HFE is not credited in the fire PRA. For actions determined to be feasible, a reliability assessment (i.e., the quantitative evaluation of the likelihood of success of the operator action) is performed as discussed in Section 5.

4.3.1 Where Feasibility Assessment Fits into the Fire HRA

Although the feasibility assessment process begins at the identification and definition stage and is a key part of the initial qualitative analysis, new information may become available during the continued development of the fire PRA model—especially during the quantification process—that would require the feasibility to be reassessed. Therefore, feasibility assessment is a continuous action step throughout the fire HRA process.

In terms of NUREG/CR-6850 [7] tasks, the fire HRA feasibility assessment performed as part of NUREG/CR-6850 Task 12 involves the following interfaces:

- NUREG/CR-6850 Task 7, Quantitative Screening, conducts the first quantification of the fire PRA model developed in Task 5 and screens out fire compartments based on quantitative screening criteria. The feasibility assessment would be performed using the best information available at that phase, and operator actions determined to be infeasible would be screened at an HEP value of 1.0.
- NUREG/CR-6850 Task 3, Fire PRA Cable Selection; Task 9, Detailed Circuit Failure Analysis; and Task 10, Circuit Failure Mode Likelihood Analysis, provide cable and circuit analyses that help determine the potential for equipment failures as well as spurious operations and indications that the operators may face during a fire event. This information factors into the availability of cues and the operability of equipment that can impact operator action feasibility.
- Knowledge from NUREG/CR-6850 Task 8, Scoping Fire Modeling, and Task 11, Detailed Fire Modeling, provides details on the fire modeling of various areas that are useful in defining scenario-specific factors affecting HRA. For example, the potential for adverse environments and timing information relative to equipment damage comes from these two tasks, providing essential input to the feasibility assessment.

The ASME/ANS PRA Standard [5] specifically discusses operator action feasibility in High-Level Requirements HR-H and HRA-D in terms of modeling recovery actions "only if it has been demonstrated that the action is plausible and feasible for those scenarios to which they are applied." HRA-D further states that this should particularly be done accounting for the effects of fires. However, the PSFs discussed under Supporting Requirement HR-G3 and listed in Table 4-1 provide the basis for the feasibility assessment factors summarized in Section 4.3.4 for evaluating whether an operator action postulated in the fire HRA is go/no-go.

In terms of documentation, some fire HRAs include a separate feasibility assessment section or attachment to facilitate its review during self-assessments and peer reviews.

4.3.2 Feasibility of EOP Actions versus Fire Response Actions

The first set of operator actions evaluated for relevance to the fire PRA are those reflected in the HFEs carried over from the internal events PRA. The vast majority of these internal events operator actions are guided by the EOP family of documents.

Following the Three Mile Island (TMI) accident, the NRC issued NUREG-0899 [14], which provides requirements for utility preparation and implementation of EOPs, including development, writing, and maintenance. The NRC then reinforced its expectations regarding EOP verification and validation (V&V) and EOP training through the issuance of NUREG-1358 [15]. In general, plant-specific documentation must be verified for power uprates, instrumentation design changes, and other plant modifications and changes to human performance protocols. In addition, the EOPs are reviewed and validated by the plant operations staff and their efficacy evaluated through simulator exercises and training drills.

While in-control room EOP actions included in the internal events PRA have already been evaluated for feasibility, it is important to reevaluate these EOP actions in the context of the fire scenario to ensure that fire-related impacts to timing or cues do not render these actions infeasible.

Fire procedures are not governed by the standard EOP set and therefore have not undergone the same level of validation. For fire response actions, the initial feasibility assessment concentrates on whether the postulated operator actions are demonstrated by the Appendix R compliance evaluations to be feasible. Further assessment can be done as the fire scenario information is better refined.

4.3.3 Special Cases in Which Little or No Credit Should Be Allowed

In Section 12.5.5.3 of NUREG/CR-6850 [7], several cases are discussed in which it was recommended that little or no credit be taken for human actions. These cases were identified prior to the efforts described in this report in order to develop more detailed HRA quantification processes. Although the conditions addressed in these special cases should still be carefully analyzed, a detailed HRA may identify situations in which it could be appropriate to take some credit for such actions. The following discussion of feasibility assessment factors generally addresses the issues associated with these cases, but because they were explicitly called out in NUREG/CR-6850, they are revisited here to avoid confusion. Each of the special cases from NUREG/CR-6850 is presented next, followed in italics by relevant caveats.

- Tasks needing significant activity and/or communication among individuals while wearing self-contained breathing apparatus (SCBAs). It is believed that communication under such conditions is difficult, and, until proven otherwise, the likelihood of success is assumed to be extremely low where levels of smoke, heat, or toxic gases are high enough to necessitate the use of SCBAs. In addition, performing numerous and strenuous actions wearing SCBAs should also be given little credit for success and at least account for delays in carrying out the actions given the likely visibility and other similar difficulties.

  Caveat: *Some newer SCBAs include devices that would allow for communication among personnel. In addition, if adequate time is available, personnel could communicate outside the area where the SCBAs are required and then return to the relevant areas to perform the important actions. Where such situations exist, a careful analysis may be able to justify crediting such actions. Performing numerous and strenuous actions while wearing SCBAs should still be credited very rarely and only when a thorough analysis is performed and justification is provided.*

- The fire could cause significant numbers of spurious equipment activations (and/or stops) and affect the reliability of multiple instruments. Actions based on such instruments and equipment should be assumed to fail unless alternative sources of reliable information can be documented and a basis for using the alternative sources can be strongly supported. The additional time, complexity, availability of procedures, and other relevant PSFs contributing to identifying and using the alternative sources of information should be considered in determining the likelihood of success.

  Caveat: *This caution still generally applies, but the issue and treatment of spurious effects are treated in detail in other sections of this report; that guidance should be followed.*

- Actions to be performed in fire areas or actions needing operators or other personnel to travel through fire areas should not be credited. Where alternative routes are possible, the demands associated with identifying such routes and any extra time associated with using the alternative routes should be factored into the analysis.

  Caveat: *If transit through a fire area is conducted after the fire is out then transit can be credited unless precluded by fire damage.*

- Actions needing the use of equipment that could have been damaged such that even manual manipulation may be difficult or unlikely to succeed (e.g., a hot short on a control cable has caused a valve to close and drive beyond its seat, possibly making it impossible to open, even manually) should not be credited.

  Caveat: *None. However, a good example of this particular issue would be "92-18 MOVs" as described in Reference 16.*

- Actions to be performed without the basic needs of operator actions—in particular, cues, procedure direction, training, necessary tools, and sufficient time—should not be credited.

  Caveat: *Supporting Requirement HR-H2 in Chapter 2 of the ASME/ANS PRA Standard [5] provides the conditions under which credit can be given, but this credit should be addressed as part of the quantification of a detailed analysis using the guidance in Appendix B or Appendix C.*

4.3.4 Feasibility Assessment Factors

Table 4-1 lists the PSFs identified in Supporting Requirement HR-G3 of the ASME/ANS PRA Standard [5] that should be evaluated for post-initiator events from the standpoint of feasibility. This list has been correlated to the criteria from NUREG-1852 [10]. It should be noted that the latter reference provides additional guidance beyond that presented in this report for conducting a thorough feasibility assessment of OMAs.

Table 4-1
Feasibility assessment criteria

ASME/ANS PRA Standard [5] PSFs (HR-G3)	Corresponding NUREG-1852 [10] Operator Manual Action Feasibility Criteria
(a) Quality (type [classroom or simulator] and frequency) of the operator training or experience	Procedures and training
(b) Quality of the written procedures and administrative controls	Procedures and training
(c) Availability of instrumentation needed to take corrective actions	Available indications
(d) Degree of clarity of cues/indications	Available indications
(e) Human-machine interface	Available indications Equipment functionality and accessibility

Table 4-1
Feasibility assessment criteria (continued)

ASME/ANS PRA Standard [5] PSFs (HR-G3)	Corresponding NUREG-1852 [10] Operator Manual Action Feasibility Criteria
(f) Time available and time required to complete the response	Analysis showing adequate time available to perform the actions (to address feasibility) Analysis showing adequate time available to ensure reliability
(g) Complexity of the required response	All criteria are related to this PSF (but, generally, this PSF is addressed under "Timing")
(h) Environment (e.g., lighting, heat, and radiation) under which the operator is working	Environmental factors
(i) Accessibility of the equipment requiring manipulation	Equipment functionality and accessibility
(j) Necessity, adequacy, and availability of special tools, parts, clothing, and so on	Portable equipment Personnel protection equipment
Blank (not listed)	Communications
Blank (not listed)	Staffing
Blank (not listed)	Demonstrations

These feasibility assessment criteria have been consolidated into the major factors described next. Any one of these factors could provide sufficient information to determine whether or not an operator action is feasible. For example, the action requires the operators to locally disconnect two breakers in the same room where the fire is occurring. However, more often, if all of these factors are considered collectively, it becomes obvious that the operator action is not feasible.

After the preliminary results have been incorporated into the model, additional resources can be used to reassess actions that were previously considered not feasible. Cases might exist in which, with enough information, the HRA analyst can make an argument that an action is feasible even though the initial information suggested that the action would be extremely difficult (or vice versa).

4.3.4.1 Sufficient Time

A key parameter for evaluating feasibility is *time*. The fire HRA must evaluate whether a given action or set of actions for a particular HFE can be diagnosed and completed within the available time. A definition of each of the timing terms such as *available time* and *required time* is provided in Section 4.6.2 along with a diagram showing the relationship of these different timing elements.

The timeline used to model operator performance consists of several elements:

1. Time delays, such as the time at which the cue occurs relative to the initiating event or the start of the event,
2. The time it takes the operators to formulate a response (i.e., to detect, diagnose, and decide on the appropriate action),
3. The time it takes to execute the response, including the time to travel to a local area, the time it takes to collect tools, and the time to don personnel protection equipment (PPE), if necessary, and
4. The total time of the scenario, from initiating event until the action is no longer beneficial.

The evaluation of the time required to complete actions can be based either on talk-throughs or walk-throughs of the procedures with knowledgeable plant staff or on simulations of the actions supported by plant staff. However, the following sources may be used in lieu of talk-throughs and walk-throughs or to supplement the assessment and provide information for determining the time required:

- Job performance measures (JPMs)
- Training exercises
- Appendix R feasibility demonstrations. As cited in NUREG-1852 [10], Section III.I.2 of Appendix R states the following:

  > Practice sessions shall be held for each shift [crew] to provide them with experience in [performing the operator manual actions] under strenuous conditions encountered [during the fire]. These practice sessions should be provided at least once per year for each [operating crew] ... [and] performed in the plant so that the [crew] can practice as a team.

- Information from the assessment of a similar action in which the following characteristics exist:
  - The actions themselves are similar
  - The timing related to when the actions have to be performed and how long it would take to implement the actions is similar
  - Locations for the actions are not so different that travel time to the locations is significantly affected
  - Similar environments exist for the locations for the actions

Timing information from the assessment of similar actions also can be used as a bounding case when it is clear that the actions being evaluated would not require more time than the similar action.

Therefore, an operator action is considered feasible if the time available to complete the action (after the cues for the action reach the operator) exceeds the time required. If it does not, the action should not be considered feasible, and the initial HEP should be either set to 1.0 or excluded from the fire PRA. When timing data are collected for crew response times, HRA analysts need to collect a range of times in addition to the “point estimate” of an average crew—especially when the required time is close to the time available. In these cases, a small change in the estimation of the time required could change the operator action from feasible to infeasible or could significantly change the reliability of the action.

The issue of complexity cited in Supporting Requirement HR-G3 of the ASME/ANS PRA Standard [5] involves several factors but is generally addressed in detailed HRA under “Timing”; the more complex the diagnosis or execution, the longer it will take to implement these tasks.

In terms of recovery actions (i.e., operator actions to correct previous operator failures), the time to accomplish the task must be adequate considering the total time available for the new recovery action after the initial system alignment was found to be ineffective in preventing challenges that could lead to core damage. Dependency issues regarding recovery actions that occur in combination with other HFEs should be evaluated as discussed in Section 6.2 to demonstrate that adequate time is available for the recovery action.

The following feasibility assessment factors could also affect the time required to complete an action (or set of actions) and should be taken into account in estimating the time required. For example, if the time required for operator diagnosis of the situation is impacted by spurious or unavailable indications, and the time needed for local manual action is impacted by fire locations and travel paths, the available time may not be sufficient to credit the HFE in the fire PRA.

Section 4.2.2 of NUREG-1852 [10] also mentions equipment access, environmental conditions, and expected variability between individuals and crews as potential contributors to timing uncertainty. It is therefore important that the analyst recognize the potential for uncertainty in the time estimates and be vigilant for cases in which a small change in the estimation of the time required could change the operator action from feasible to infeasible.

4.3.4.2 Sufficient Manpower

Feasibility assessment of staffing for fire HRA includes an evaluation of the availability of a sufficient number of trained personnel without collateral duties during a fire, such that the required operator actions can be completed as needed. Therefore, because a fire could occur at any time, all operating shift staffing levels should include enough trained personnel to perform the required operator actions. If there are not enough crew members available to complete the action (i.e., the number of people required for each task exceeds the crew available), the operator action should not be considered feasible, and the initial HEP should be either set to 1.0 or excluded from the fire PRA.

Staffing issues such as the following should be considered in the feasibility assessment:

- As pointed out in NUREG-1852 [10]:

  > [A]n operator should not serve as both a Fire Brigade member and be responsible to perform an operator manual action during a fire at the same time (i.e., the operator should not serve both functions concurrently). The operator could serve as a Fire Brigade member on shift provided another operator had the manual action responsibility that same shift. The intent is that an individual who could be called upon to perform operator manual actions should not, for example, also be a member of the Fire Brigade for the same fire, or have other duties that would interfere with the ability to perform the operator manual action in a timely manner.

- If personnel will have to be summoned from outside the MCR, an assessment of how long it will take them to get to the control room should be performed, considering the likely starting locations for the personnel. The analysis should consider the potential that the personnel might be in remote locations from which it may be difficult to egress and that the

personnel may have to complete some actions before they can leave an area. If the actions will involve multiple staff in certain sequences, these activities, their coordination, and their associated communication aspects should be assessed.

- Consideration should be given to the workload of the MCR crew while directing and coordinating multiple teams involved in executing manual actions, particularly if the MCR crew has other significant responsibilities at the same time.

4.3.4.3 Primary Cues Available/Sufficient

This factor addresses the instrumentation and/or alarms used as the cue(s) for the operator response to answer the following question: Has the fire impacted the cue(s) such that diagnosis is not possible?

In general, HRA assumes that all operator actions are taken in response to a cue. If there is no cue, the operators will not respond. Cues can be instrumentation, a procedure step, or a plant condition. A fire can impact the instrumentation; if the fire fails all instrumentation, it is assumed that the operator action will not be successful.

One of the key issues regarding instrumentation in the fire context is whether the fire can cause spurious indications that lead the operator to take an inappropriate action.

Supporting Requirement HRA-B4 of the ASME/ANS PRA Standard [5] states the following Capability Category II requirement:

> INCLUDE HFEs for cases where fire-induced instrumentation failure of **any single instrument** could cause an undesired operator action, consistent with HLR ES-C of this Part and in accordance with HLR-HR-F and its SRs in Part 2 and DEVELOP a defined basis to support the claim of non-applicability of any of the requirements under HLR-HR-F in Part 2.

Note 2 to this supporting requirement states the following:

> The intent of this requirement is to recognize that in cases where instrumentation required for an operator action could be affected by a fire, the implication is that there is a potentially significant likelihood that the operator will either fail to perform an action or take an inappropriate action (e.g., shut down a pump because of a spurious pump high temperature alarm) due to the failed instrumentation. This requirement is to ensure that these types of HFEs are not overlooked in recognition that the corresponding HEPs could be high.

This single-instrument criterion looks at single indications that, if failed, could lead to an error of commission (EOC) or an error of omission (EOO). The indicators associated with each operator action in the fire PRA model are identified and provided to the circuit analysis task early on so that cabling associated with each indicator can be routed. For each cable-route area (e.g., fire initiator), a basic event is defined. For cases in which this fire initiator could cause failure of an indication required for the operator to recognize the need for action, the event is included in the fire PRA model under an OR gate with the HFE corresponding to the action that relies on this indication. In so doing, when fire in this cable-route area fails the key indication, the associated human action within the fire PRA model is also effectively failed. If the fire could cause a failure that would lead to an expectation of undesired operator action (i.e., an EOC), the fire initiator is typically included under an OR gate that also includes failure of the equipment that would be affected by the undesired action, so that it is treated as unavailable.

The circuit analysis task is required to evaluate the failure modes of each cable relevant to the indicator functional states and is a detailed, complex, and time-consuming process that often drives the fire PRA schedule and resources. In addition, the fire modeling task that evaluates ignition likelihoods by fire area generally lags behind the fire PRA modeling task. For this reason, the initial feasibility assessment associated with spurious indications is likely to require assumptions or qualitative assessments on the part of the analyst to account for indication uncertainty. The following is an example of such a qualitative evaluation:

> The primary cue in this scenario is pressure. There are numerous redundant and functionally redundant pressure instruments available to operators in the MCR, remote shutdown panels, and Reactor Building cabinets. Therefore, fires which impact the relevant pressure instruments are expected to be rare.

Another such assessment involves the review of the EOPs. For example, in the case of an event such as "Operator Fails to Start a Charging Pump," an EOP will direct the operator to ensure that two charging pumps and both RHR pumps are operating. Operators will then check the control board to verify that the charging pump(s) are operating as required. Charging pump indications include discharge pressure indication, discharge flow indication, amp meter indication, and red indicating lights. In addition, various annunciator board alarms and lights will indicate that the charging pump is running. Therefore, multiple indications are considered available for this action, and no single indication is considered to impact the feasibility of the operator action.

Many plants include tables in their fire procedures that identify the instruments most likely to have been impacted by fire and provide alternative instruments for the operators' use in parameter verification and scenario diagnosis. These tables provide valuable information to the fire HRA for instrument vulnerability evaluations.

When detailed fire modeling and circuit analysis are further along, a more thorough analysis of spurious instrumentation impacts on operator diagnosis and execution can be made.

The timing of the HFE should also be taken into account during the evaluation of instrumentation unavailability impact on operator action feasibility; hot shorts that occur soon after the fire may no longer be an issue during long-term scenarios when diagnostic cues are actually needed for operator success.

4.3.4.4 Proceduralized and Trained Actions[7]

The feasibility analysis should include evaluation of the quality of procedures based on their ability to accomplish the following:

- Assist the operators in correctly diagnosing the fire event and plant response (with consideration of potential impacts to indications)
- Identify the appropriate preventive and mitigative manual actions, including the tools or equipment that should be used and where the action should be taken
- Reduce potential confusion from fire-induced conflicting signals, including spurious actuations

[7] or justified exceptions

Training quality should be evaluated based on its ability to do the following:

- Engender operator familiarity with potential adverse conditions arising from a fire event as well as the actions and equipment needed to mitigate the event
- Allow operators to be prepared to handle departures from the expected sequence of events
- Provide the opportunity to practice operator response and bolster confidence that these duties can be performed in an actual fire event

Certain operator actions may be identified as *skill-of-the-craft* and credited on that basis although not specifically proceduralized. However, the feasibility of these actions would have to be justified through the performance of walk-throughs or talk-throughs or by an evaluation of existing JPMs for fire safe shutdown. This is consistent with ASME/ANS PRA Standard [5] Supporting Requirement HR-H2, which states that recovery actions can be credited if "a procedure is available and operator training has included the action as part of crew's training, or justification for the omission for one or both is provided." It should also be noted that recovery actions may be addressed in specialized procedures for which the operators may not receive extensive training for the particular case being analyzed in the fire PRA.

4.3.4.5 Accessible Location

If any of the required critical tasks is in the same location as the fire (or the same zone, if the fire is located in a large room) or it is known that the operators will not be able to reach the location(s) because of the fire, the operator action should not be considered feasible, and the initial HEP should be set to 1.0.

The evaluation of "accessibility" mandates an evaluation of the travel path required for local manual actions given the location of the fire and how such accessibility might be compromised by the fire initiating event. It may be necessary to postulate alternative actions that can be taken in other locations to achieve the same goal or function, such as pulling fuses rather than locally actuating valves, as long as these alternative actions are verified as feasible through operator interviews and walkdowns. Travel paths should be identified and documented using the plant layout diagrams (indicating the specific room, stairwell, and doorway numbers) and verified with operations staff to ensure correctness for the given fire scenario. Analysts should consider including radiation hotspots and radiation areas as an additional, potential information source in discussing possible impact on travel paths. The impact of alternative travel paths on the timing of fire HFE execution task must also be considered because, for short timeframe actions, the addition of further travel time could render the action infeasible.

Environmental and other effects that might exist in a fire scenario include the following:

- Smoke and toxic gas effects, which could slow the implementation time for the action and may require the operators to wear SCBA
- Obstruction, such as from charged fire hoses
- Heat stress
- Radiation. For the feasibility analysis, the analyst needs to determine whether the radiation level or rating of an area would preclude access or otherwise prevent the action from being feasible. For example, fire could damage equipment where contamination (radioactive particulate) is a potential issue in the location in which the action needs to be taken; as a result, operators would need to don personnel protective clothing (which takes extra time) before going to this location.

- Locked doors. The fire may cause electric security systems to fail locked. In this case, the operators will need to obtain keys for access. If all operators do not routinely carry the keys to access a secure area, the HRA analyst must ensure that there is enough time for the operators to obtain access. Normally locked doors should also be considered.

All of these effects should be considered possible, perhaps even likely, when determining the feasibility of performing a manual action in a fire situation.

4.3.4.6 Equipment and Tools Available and Accessible

To access and manipulate plant equipment during local manual actions, portable and special equipment may be needed and should also be considered from the standpoint of feasibility. Items falling under this category according to NUREG-1852 [10] include keys to open locked areas (especially in light of tighter key controls that some plants may have implemented in response to security needs) or manipulate locked controls, portable radios, portable generators, torque devices to turn handwheels, flashlights, ladders to reach high places, and electrical breaker rack-out tools.

Protective clothing, gloves, and SCBAs may be needed to allow the operator to access equipment impacted by the fire when smoke propagates beyond the immediate fire area. Crediting the feasibility of the local action requires that this equipment be readily available and functional; in a known and designated location; and able to be located, accessed, and donned by plant personnel during an actual fire.

Often this special gear and its locations are documented in specific procedures or in the appendices to plant fire procedures.

Training on the use of this equipment is important to crediting feasibility, and the training quality and frequency should be noted during the feasibility assessment.

4.3.4.7 Relevant Components Are Operable

As stated in NUREG-1852 [10]:

> This criterion addresses the need to ensure that the equipment that is necessary to enable implementation of an operator manual action to achieve and maintain fire hot shutdown is accessible, available, and not damaged or otherwise adversely affected by the fire and its effects (such as heat, smoke, water, combustible products, spurious actuation).

Implicit in this feasibility criterion are the quality of the human-machine interface (HMI) and the ability of the operator to properly evaluate and address the fire conditions in order to maintain plant functionality. It also addresses the equipment that may need to be manipulated to mitigate a fire scenario and the considerations of the fire-related damage state that may even prevent that equipment from being actuated manually.

If the fire has damaged the equipment such that it will not function even if the operator takes the appropriate action (such as motor-operated valves [MOVs] affected by NRC Information Notice 92-18 [16]), the operator action should not be considered feasible, and the initial HEP should be set to 1.0. For example, if the auxiliary feedwater pump is affected by fire, the operator will not be able to restore the pump locally.

4.4 Quantification Method Selection

One of the important insights from NRC's *Evaluation of Human Reliability Analysis Methods Against Good Practices* (NUREG-1842 [17]) is that the best quantification results are obtained when the outputs of the HRA qualitative analysis (e.g., PSFs) are well matched with the HRA quantification method chosen. For example, if the qualitative analysis shows that the time available for operator action is a dominant factor on operator performance, choosing an HRA quantification method that is based on time-reliability correlation would be appropriate. Conversely, if the selected HRA quantification method does not address an important PSF that was identified during qualitative analysis, the usefulness of the HRA quantification results is likely to be limited.

The intent of this report is to provide HRA quantification methods that are suitable to address the factors most likely to influence operator performance in fire contexts. In addition, the authors have developed specific criteria for using one of the quantification methods (i.e., the scoping approach) so that the user understands the limits and capabilities of this quantification approach. Beyond this guidance, the authors recommend that the user be guided by the specific needs for each fire PRA scenario and HFE, as indicated by the qualitative analysis, to make choices regarding HRA method selection.

4.5 Development of an HFE Narrative

Based on recent HRA research, one of the best ways for an HRA analyst to communicate what is understood about an HFE and its associated PRA scenario is to develop an "operational story" or, as described here, an HFE narrative. The narrative integrates and relates the elements of the PRA context to other information, such as general performance shaping factors, as a way to better understand the plant response and how it translates to scenario-specific performance.

This section describes some of the information (both "raw" and assessed) that could be part of an HFE narrative. Some or all of this information can serve as input to HRA quantification (either directly or indirectly, depending on the method) and/or as a qualitative analysis product itself (e.g., part of the HRA documentation). The following HFE narrative elements are discussed in this subsection:

- Fire-induced initiating event
- Accident sequence (preceding functional failures and successes)
- Timing information
- Accident-specific procedural guidance
- Availability of cues and other associated indications that may be needed to identify necessary actions, as well as those that might subsequently enable the operators to detect the need for a correct action that has been omitted or performed incorrectly
- Preceding operator errors or successes in sequence
- Operator action success criteria
- Physical environment

Additional discussion of PSFs (the details of which are likely to be needed in developing a detailed HFE narrative) is provided in Section 4.6.

For existing internal events HRAs, many of their definitions will remain unchanged for the fire HRA; however, these definitions should be verified to ensure that all PSFs are appropriately accounted for in the context of fire. In addition, the scoping approach to quantification and the EPRI HRA approach [2] both assume that the internal events HRA meets Capability Category II of the PRA Standard [5]. This assumption should be verified before additional analysis is performed. For new actions identified by the fire HRA, each HFE must be defined to this level of detail regardless of whether the action is risk-significant or non-risk-significant in order to meet ASME/ANS Standard Requirement HR-F2.

4.5.1 Fire-Induced Initiating Event

For fire PRA, the initiating event is a fire that causes a reactor trip. The reactor trip can be caused either by the fire itself or by fire-induced equipment failures that lead to initiators such as loss of offsite power (LOOP) or LOCA from stuck open power-operated relief valve (PORV), which will also lead to an automatic or manual trip of the reactor. The type of initiating event, such as transient or LOCA, will affect the overall time available for response as well as the procedural path to the modeled HFE.

4.5.2 Preceding Functional Failures and Successes for the Accident Sequence

Following the reactor trip, functional failures and successes are identified to understand how all of the PSFs could impact operator performance. This step also identifies the operator action in the context of the fire PRA. For existing EOP actions, the functional failures and successes will typically follow those in the internal events PRA but need to be verified. The PRA analyst is not always aware of the specific HRA details, and they could unintentionally change the sequences of events on which the internal events actions were based.

Identification of the accident sequence will also identify any potential dependencies among HFEs.

4.5.3 Timing Information

In the "Identification and Definition" step described in Section 3, the timing information about the feasibility of the action was identified in a qualitative way by asking, "Is there enough time to complete the action?" A definition of each of the timing terms such as *available time* and *required time* is provided in Section 4.6.2 along with a diagram showing the relationship of these different timing elements. For quantification, however, the following detailed timing information needs to be defined:

- The total time available: the period from initiating event (usually reactor trip) until an undesired end state
- The time at which the cue for the action occurs relative to the initiating event
- The time it takes the operators to formulate a response (i.e., detect, diagnose, and decide)
- The time it takes to execute the response, including the time required to travel to a local area, if necessary

This information needs to be defined in the context of the fire (see Section 4.3.2). The total time available and the time at which the cue occurs are typically obtained from thermal-hydraulic calculations or vendor-specific studies.

Using the guidance presented in Section 4.3.4, the time it takes for operators to formulate and execute a response can be obtained from a variety of plant-specific sources, including the following:

- Plant-specific simulator data
- Plant-specific operator interviews
- Job performance measures (for actions outside the control room)
- Estimation

Often, it will be necessary to draw on combinations of these approaches to obtain the most realistic estimates possible.

For existing EOP actions, the timing information may be similar to the internal events PRA but may need to be adjusted to account for fire impacts such as the following:

- Delays in implementing EOP procedures resulting from first implementing fire procedures
- Increases in manipulation time resulting from additional workload
- An increase in cognitive response resulting from misleading or unclear indications
- Increases in manipulation time resulting from additional travel time for local actions

See Section 4.6.2 for guidance on the collection of timing data, including considerations relating to ranges of and uncertainty in response times.

4.5.4 Accident-Specific Procedural Guidance

For each HFE, the procedural guidance needs to be identified. This guidance includes not only identifying the procedures, but also identifying how the operators will arrive at the specific procedure step. For fire PRA, procedural guidance may be available in both the fire procedures and the EOPs. If procedural guidance is unavailable, an HEP for the HFE can still be developed by using the ASME/ANS PRA Standard [5] high-level and supporting requirements of HR-H.

4.5.5 Availability of Cues and Other Indications for Detection and Evaluation Errors

The cues should be defined at a functional level and by the specific instruments expected to be used. The definition includes how the instrumentation is impacted by fire; secondary cues (supplemental aids) that could impact recovery also are to be identified. In fire scenarios, it should be confirmed that the cues and indications credited for the relevant internal events operator actions are still valid. Note that the fire impact may directly affect the cues and instrumentation.

In addition to ensuring that a minimal set of cues is available to conduct the operator action, the fire PRA can also provide information regarding the additional fire impacts on instrumentation

that can be a potential distraction to the operator. This additional information can be used during the quantification of HEPs and/or identified as a potential source of modeling error.

4.5.6 Preceding Operator Errors or Successes in Sequence

Preceding operator errors or successes are defined in order to understand the workload and potential stress levels. They also aid in understanding the procedural paths followed by the operators. This definition is developed through a review of the event trees and fault trees and may require interaction with the fire PRA analyst. For fire response actions, the HRA analyst will need to work with the fire PRA analyst to ensure that the fire response actions are incorporated appropriately.

4.5.7 Operator Action Success Criteria

The specific operator tasks required for success need to be defined. From the operator action success criteria, the failure model can be developed. The development of operator action success criteria consists of subtasks for cognition and execution; the cognition subtask is further divided into detection, diagnosis, and decision making. Either an alarm or a procedure step will provide a cue that will initiate the cognitive response and fulfill the detection and diagnosis portion of cognition. The decision making is typically related to carrying out a portion of a procedure. The execution tasks are associated with the manipulation of components in following the procedure after the operator's response strategy has been decided. Execution tasks are typically steps in the procedure.

4.5.8 Physical Environment

Because the fire could have a significant impact on the physical environment in which the operator actions are being performed, the fire location must be identified and any changes to the operators' work environment must be considered, for example:

- The fire location may require the operators to take a detour when performing local actions, or the actions may require that the operators wear SCBA gear.
- The fire may cause a loss of power, which could fail-closed some locked doors. It should be verified that the operators can gain access (in the required time) to locations.

4.5.9 Impact of the Fire PRA Task on Narrative Elements

Each of the preceding narrative elements can be defined in various levels of detail, depending on what is required in the fire PRA task. For example, in Task 7a of NUREG/CR-6850 [7], each fire area is quantified for complete room burnup. At this stage of the fire PRA development, screening values such as those provided in NUREG/CR-6850 would be applicable because the purpose of Task 7a is to screen out fire compartments based on quantitative screening criteria. In addition, the fire response scenarios may not be sufficiently defined for a complete detailed HRA to be performed; for example, the detailed timing information will come from Task 8, which may or may not be completed. Finally, as the fire PRA model is developed, the specific sequences of events may change.

When a room is completely burned up, any instrumentation located in the fire area being quantified is assumed failed (unless it is known to be protected); any HFE requiring this

instrumentation should therefore be assumed failed. In addition, if the HFE requires a local action to be performed in the fire location, the operator action should not be credited.

Beginning in NUREG/CR-6850 Task 8 and continuing through the early quantification of Task 11 for potentially risk-significant compartments, the fire PRA is quantified using a scoping approach. At this stage of the fire PRA development, the HFEs can be quantified using screening, scoping, or detailed analysis. Scoping for HRA quantification is considered more detailed than NUREG/CR-6850 screening but less detailed than a detailed HRA quantification. Many HFEs have not been screened out at this point and performing a detailed analysis could be resource intensive because more HFEs will be screened out as the fire PRA is further refined.

HFEs required for final quantification in Task 12 of NUREG/CR-6850 must be defined to the greatest level of detail because these HFEs are potentially risk-significant to the fire PRA. Cues and indications must be clearly identified and their fire impacts clearly understood. The timing information must be plant specific, and the preceding operator successes and failures as well as procedural guidance must be identified.

Guidance for the treatment of MCR abandonment, preemptive operator actions, and spurious indications is provided in Sections 4.8, 4.9, and 4.10, respectively.

4.6 Performance Shaping Factors

PSFs are interdependent, and their impact on HEPs is complicated. However, for practical analysis, PSFs are often treated independently and are discussed as such next. The purpose of this section is to describe the PSFs that must be addressed for fire HRA. The discussion is intended to provide understanding and support (an important knowledge base) for the specific treatment of PSFs included in the scoping and detailed HRA methods. This section provides an overview of considerations for fire HRA; in many cases, the same guidance for internal events HFEs can also be applied to fire and is reproduced here for clarification. The implementation of these PSFs is discussed in the appropriate section for quantification.

The following PSFs are relevant for fire HRA:

- Cues and indications
- Timing
- Procedures and training
- Complexity
- Workload, pressure, and stress
- Human-machine interface
- Environment
- Special equipment
- Special fitness needs
- Crew communications, staffing, and dynamics

This list is a combination of PSFs listed in NUREG/CR-6850 [7], NUREG-1792 [6], NUREG-1852 [10], and the ASME/ANS PRA Standard [5].

4.6.1 Cues and Indications

Cues and indications are necessary because all required operator actions are predicated on them. Without cues or indications, the operators have no prompts that some action is required, and therefore no operator action can be credited.

In fire scenarios, it must be confirmed that the cues and indications—which are credited for the relevant internal events operator actions—are still valid. For example, an operator action credited in response to certain indications in the internal events PRA may not still be credible if the indications are impacted by the fire or the associated instrumentation cable routing is unknown. For such actions to continue to be credited, it must be shown either that alternative (redundant or diverse) indications are not impacted by the same fire or that the minimum required instrumentation is sufficiently protected and procedurally identified as such. NRC Information Notice 84-09 [18] lists the minimum instrumentation required to be protected by the Appendix R safe shutdown scheme:

- Diagnostic instrumentation for shutdown systems
- Level indication for all tanks used
- Pressurizer (PWR) or reactor water (BWR) level and pressure
- Reactor coolant hot-leg temperatures or core exit thermocouples and cold-leg temperatures (PWR)
- Steam generator level and pressure (wide range; PWR)
- Source range flux monitor (PWR)
- Suppression pool level and temperature (BWR)
- Emergency or isolation condenser level (BWR)

The safe shutdown list of protected equipment will need to be compared to instruments credited in the fire HRA, and any instruments not included in the safe shutdown list will need to be added to the component selection list for cable tracing. For example, the safe shutdown analysis does not consider mitigations of a fire causing a LOCA and may not require refueling water storage tank (RWST) level indication as part of its analysis. For fire PRA, RWST level indication would be needed to credit operator actions for switchover to recirculation.

NUREG-1792 [6] notes that, in the internal events HRA, it is often assumed that the cues and indications are adequate because of the redundancy and diversity in a typical control room. However, in scenarios in which redundancy and/or diversity could be impacted (such as loss of DC power or fire), this assumption must be verified.

NUREG-1852 [10] notes that, in addition to the SSCs needed to directly perform the desired function, instrumentation and cues are needed to provide diagnostic indications relevant to the desired OMAs. These indications, to the extent required by the nature of the OMA, may be needed to enable the operators to determine which manual actions are appropriate for the fire

scenario, to direct the personnel performing the manual actions, and to provide feedback to the operators—if not already directly observable—to verify that the manual actions have had their expected results and that the manipulated equipment will remain in the desired state.

Spurious indications are of special concern in fire scenarios because they can cause confusion or even prompt the operators to take an inappropriate action. Indications that are not verified for validity could prompt the operators to perform an inappropriate action (or fail to take a needed action) if a spurious indication appears to be valid within the context of the scenario. Spurious indications that are clearly inconsistent with the scenario context would likely be identified as invalid by operators, given an awareness of potential erratic instrumentation behavior as a result of the fire. For example, spurious high-temperature readings from core exit thermocouples in a PWR would be identified as invalid if there had not been a trend of increasing temperature, if hot- and cold-leg temperatures are constant, or if subcooling margin indications are constant.

The identification of the invalid indications will add to the time required to perform necessary actions and, at worst, cause the operators to not take appropriate actions or to perform procedure-directed actions under the wrong circumstances or at the wrong time. An example of this would be if the operator follows a procedure in response to a spurious high-temperature alarm and shuts down an otherwise operable pump because of the spurious indication. Consideration must be given to the spurious events, their potential effects with each postulated fire, and how they might affect subsequent operator performance relative to the HFEs being analyzed.

Analysts sometimes justify not modeling potential EOOs or EOCs on the basis that operators would be able to identify invalid indications based on the context (as noted previously). Such arguments must be well documented and confirmed by appropriate plant staff (e.g., operators and trainers).

For MCR abandonment actions, the crew will likely have limited familiarity with the ex-CR panels and the way in which cues for actions are presented. Furthermore, the HMI of these panels may not be as good as that in the MCR. These issues must be considered in evaluating the adequacy of relevant cues for post-MCR abandonment actions. For example, in applying the scoping approach, analysts will need to ensure that there are cues on the ex-control room panels consistent with those indicated by the procedures. In addition, in cases of MCR abandonment or the use of alternate shutdown approaches, the general effects of crews no longer having access to all of the information in the MCR need to be evaluated.

4.6.2 Timing

Figure 4-1 presents a structured timeline for an individual HFE. This timeline is composed of several elements to capture the various aspects of time during the progression from initiating event until the time at which the action will no longer succeed. Developing the timing information according to this timeline is useful in that it applies to all quantification methods.

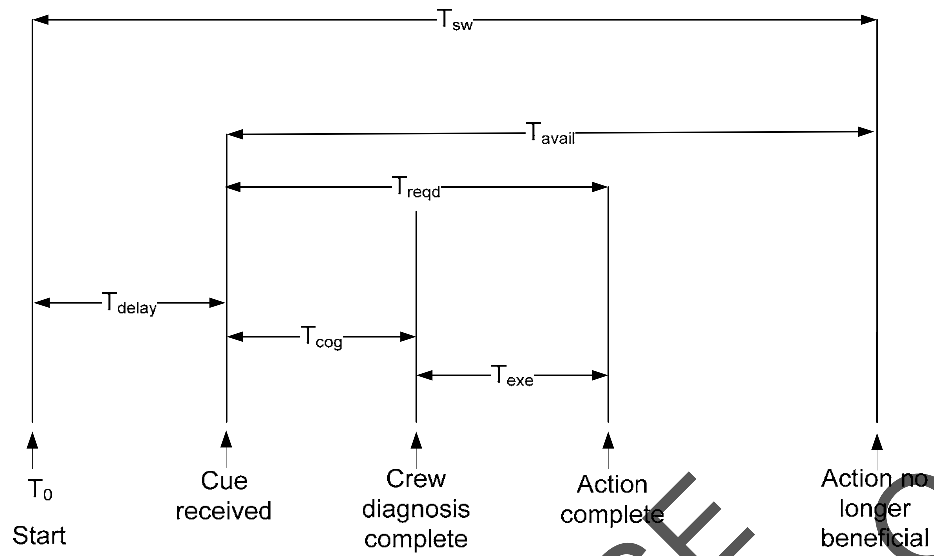

Figure 4-1
Timeline illustration diagram

The terms associated with each timing element are defined mathematically next and then further described in the subsequent text:

T_0 = start time = start of the event

T_{delay} = time delay = duration of time it takes for an operator to acknowledge the cue

T_{sw} = system time window

T_{avail} = time available = time available for action = $(T_{sw} - T_{delay})$

T_{cog} = cognition time consisting of detection, diagnosis, and decision making

T_{exe} = execution time including travel, collection of tools, donning of PPE, and manipulation of relevant equipment

T_{reqd} = time required = response time to accomplish the action = $(T_{cog} + T_{exe})$

Structuring the timeline in this way allows the analyst to demonstrate, among other things, the feasibility of the action from the perspective of timing. Section 4.3.4.1 provides guidance on developing the feasibility assessment. Specifically, the guidance indicates that the operator action is feasible when the time required to complete the action is less than the time available. The time available (T_{avail}) consists of the system time window (T_{sw}) minus any time delays (T_{delay}), for example, time delay until the relevant cue for the action is received. The time required (T_{reqd}) consists of the time to recognize the needed action (T_{cog}) and the time to execute the action (T_{exe}); this is also called the *crew response time*. Each of the timing elements, including the start time, is defined next.

Start time. In Figure 4-1, T_0 is modeled as the start of the event. For fire HRA, T_0 can be either reactor trip (which is commonly the starting point for internal, non-fire PRA) or the start of the fire. The fire PRA typically assumes that reactor trip and the start of the fire occur at the same time unless scenario-specific factors show a significant difference.

System time window. T_{sw} is defined as the system time window and is the time from the start of the event until the action is no longer beneficial (typically when irreversible damage occurs, such as core or component damage). T_{sw} is typically derived from thermal-hydraulic data and, for HRA quantification, is considered to be a static input. The system time window represents the maximum amount of time available for the action.

Delay time. T_{delay} represents the time from the start (typically the initiating event) until the time at which the operators acknowledge the cue. This is a function of the fire damage and the plant response, which includes taking into account any procedure delays or delays in responding to the cue. If the cue, for example, is a step in the fire procedure, T_{delay} would be the time it takes the operators to reach that step in the fire procedure. If the cue is an alarm that annunciates when a low tank level is reached, T_{delay} would be the time it takes to drain the tank until the alarm annunciates and the operator acknowledges the alarm. If the implementation of the appropriate procedures is delayed because the fire caused the control room crew to be actively implementing (or taking into consideration) multiple procedures such as the EOPs and the fire procedure(s), the guidance is to systematically increase the delay time when updating existing internal events HFEs for use in the fire PRA. Similarly, if a particular fire area or fire scenario causes spurious alarms, indications, or the actuation of components, the guidance is to systematically extend the delay time when updating existing internal events HFEs for use in the fire PRA. The delay time following fire initiating events is a source of modeling uncertainty in the current state of the art in fire PRA.

In addition to procedural and instrumentation impacts on the delay time, NUREG-1852 [10] suggests that time available should consider unique fire-specific uncertainties such as the nature of the fire (fast or slow), fire detector response times, and airflows that can impact fire growth. In this NUREG, these factors are modeled as part of the time delay. However, because fire detection and suppression in NUREG/CR-6850 [7] are currently based on empirical non-suppression data curves, these factors are often implicitly accounted for and may not be available for explicit consideration in the fire HRA.

Cognition (recognition) time. T_{cog} is defined as the nominal time for cognition and includes detection, diagnosis, and decision making. T_{cog} is best obtained by simulator observations. For fire response actions, the diagnosis will typically be made in the control room and the execution local—and therefore still possible to observe the cognition time from simulator observations. If there is a need to model local cognition, cognition time can be obtained by talk-throughs and/or walk-throughs (see Sections 4.3.4.1, 4.11.1, and 4.11.2).

For scenarios in which no instrumentation is impacted by fire, the cognition time would be similar to internal events time because the EOPs are symptom based (not initiator based). It is expected that the operators will trust their instrumentation unless there is a compelling reason not to. For cases in which the cues are partially impacted by the fire, the diagnosis and decision making may be more difficult given the extent of the fire damage. These are the cases for which simulator observation would be most beneficial.

Execution time. T_{exe} is the nominal time required for the execution of the action. *Execution time* is defined as the time it takes for the operators to execute the action after successful diagnosis. The execution time includes transit time to the local components, time to collect tools and don PPE, and time to manipulate the local components. The transit (travel) time could be significantly impacted by the fire location. Useful inputs to develop T_{exe} can be obtained from JPMs or by walk-throughs or talk-throughs with the operators (see Sections 4.11.1 and 4.11.2).

For control room actions, the guidance is to use the same T_{exe} from the internal events development (often called the *manipulation time* because there is typically no need for tools or PPE) for the fire event, unless the fire has impacted the control room (i.e., no smoke or hazard is present that would make manipulation more difficult).

When timing data are collected for crew response times, HRA analysts should strive to collect a range of times in addition to the "point estimate" of an average crew; this is especially important when the required time is close to the time available. Although the availability of operations staff may be limited, it is important to interview several operators for cases in which a small change in the time estimation could render a feasible operator action infeasible or significantly impact the resulting HEP. For example, the time required for an operator to locally align a particular valve may be 15–20 minutes for the quickest response but in all cases would be complete within 35 minutes (confirmed by a JPM in which 65 crews have completed the action within 35 minutes on the JPM card). In this example, the 35-minute response time—not 20 minutes–should be used. For actions that occur well after the initiating event or for actions with a long time window, a bounding estimate can often be useful. Using the same example, if the system time window is 6 hours and the cue occurs at 90 minutes, knowing a range of times may be interesting—but in such a case a bounding statement would typically be adequate (e.g., using the estimate of 35 or 40 minutes directly), and the analyst would not need to find the shortest response time.

As noted, potential uncertainty in the timing data is important for cases in which a small change in the estimation of the time required could change the operator action from feasible to infeasible or significantly change the reliability of the action. In both the scoping method and the EPRI HRA approach [2] for quantification, certain "tipping points" might exist in which a few additional minutes in the estimate can push the action into a different time margin regime. In these cases, it is recommended that the analyst choose to initially use the more conservative timing data (and resulting HEP) and refine the data later if the HFE significantly impacts the fire PRA model quantification results. Alternatively, the analyst could run several test cases to evaluate the impact of timing variability and perhaps quantify the HFE with separate timing cases if the impact is strong enough to warrant it. ATHEANA [3, 4] does not involve predefined "tipping points," although cases with a similar implication might be identified as part of the expert elicitation quantification process. As part of the typical ATHEANA process (see, for example, Sections C.3.3 and C.3.4), differences in timing that could result in the assignment of dramatically different HEPs by experts should be identified and carefully explored. Such differences in timing and associated HEPs can be treated in two ways in ATHEANA: 1) capture in the distribution of HEPs according to the typical ATHEANA quantification process or 2) definition of two or more HFEs, each with its own probability distributions.

For the quantification of HEPs in the scoping analysis (see Section 5.2), the timing terms defined previously are used to calculate the time margin. *Time margin* is defined as the ratio of time available for the recovery action to the time required to perform the action (T_{cog}+T_{exe}); it is calculated as follows:

$$\text{Time Margin (TM)} = \frac{T_{avail} - T_{reqd}}{T_{reqd}} \times 100\% \qquad \textbf{Equation 4-1}$$

$$\text{Time Margin (TM)} = \frac{\left[\left((T)_{sw} - T_{delay}\right) - \left(T_{cog} + T_{exe}\right)\right]}{\left(T_{cog} + T_{exe}\right)} \times 100\% \qquad \textbf{Equation 4-2}$$

Time margin is explicitly considered in the scoping quantification to account for potential shortcomings in the plants' ability to simulate plant conditions during fires and the potential variability in crew response times. In addition, different time margins may be required if the presence of certain conditions (e.g., short versus long timeframe events or simple versus complex actions) suggests the potential for greater sensitivities to the effects of the fire or greater variability in crew response times.

4.6.2.1 Background Information on Timing Considerations from HRA Reference Documents

NUREG-1792 [6] and NUREG/CR-6850 [7] point out that timing can be influenced by many other PSFs. In particular, the time to perform an action is a function of (at least) the following factors that could be impacted by fire:

- Crew
- Cues
- Human-machine interface
- Complexity of action involved
- Special tools or clothing
- Diversions and other concurrent requirements
- Procedures
- Environmental conditions

NUREG/CR-6850 provides the following examples of how the overall estimates of the time available and the time required to complete the desired action can be influenced by other PSFs during a fire:

- A spurious closure of a valve used in the suction path of many injection paths may need quick detection and response by the crew.
- Use of less familiar or otherwise different procedure steps and sequencing could change the anticipated timing of actions in response to a fire.
- Interfacing with the fire brigade may delay performing some actions.
- The desired actions may be more complex and/or lead to increased workload relative to the internal events response (e.g., disabling an equipment item before repositioning it as opposed to simply repositioning it during an internal event).
- Accessibility issues, harsher environments, and/or the need for other special tools may impact the overall timeline of how quickly actions normally addressed in response to internal events can be performed under fire conditions.
- Potential fire growth and suppression could alter equipment failure considerations from those considered for internal events.

For MCR abandonment actions or alternate shutdown approaches, enough time must be allowed for the operators to perform the required actions to achieve and maintain hot shutdown from an alternate shutdown location(s) or panel(s). Included in this required time is an allowance to reach the required destination, diagnose the problem, and execute the required solution. Uncertainties in other factors that could affect the completion of actions within the time available (such as the environmental conditions discussed next and elsewhere in this report) must be considered in determining the HEPs.

Section 4.2.2 of NUREG-1852 [10] mentions equipment access, different travel paths resulting from the fire location, and expected variability among individuals and crews as other contributors to timing uncertainty.

4.6.3 Procedures and Training

Real-world events under complex situations have shown that operator response is improved by having procedures available. Operational experience also has shown that complex situations may slow the typical response to procedures or may lead to the selection of the wrong procedure, especially for scenarios in which instrumentation is affected or when training does not cover the specific situation. The fire HRA quantification methods provided in this report treat the use of appropriate procedures as the most desirable response to fire scenarios. However, the current state of the art in fire procedure and fire training development is improving and evolving as insights from the fire PRA models and/or the transition to NFPA 805 occur.

As stated in NUREG-1852 [10], plant procedures have three roles that can contribute to successful operator performance during a fire:

1. The procedures can assist the operators in correctly diagnosing the type of plant event that the fire may trigger (usually in conjunction with indications), permitting the operators to select the appropriate operator manual actions.
2. The procedures direct the operators to the appropriate preventive and mitigative manual actions.
3. The procedures attempt to minimize the potential confusion that can arise from fire-induced conflicting signals, including spurious actuations, minimizing the likelihood of personnel error during the required operator manual actions.

As stated in NUREG/CR-6850 [7], depending on the fire, the operators may need to use procedures or controls other than EOPs typically used in response to internal events. Implementing unfamiliar or multiple procedures simultaneously could lead to confusion. In some cases, especially for some ex-CR actions, procedures might not exist or be readily retrievable or might be ambiguous in some situations. The analyst must check the adequacy and availability of these other procedures that would be needed to address the fires modeled in the fire PRA. Obviously, the amount of training the crews receive on implementing the procedures and the degree of realism will be a critical factor.

For fire HRA, talk-throughs with operations and training staff can be helpful in uncovering difficulties in using the relevant procedures. In contrast to EOPs, the fire procedures are not always standardized, and their use is sometimes at the discretion of the shift supervisor. Understanding when and how the procedures are implemented will drive other PSFs such as timing, cues and indications, workload, stress, and complexity.

If any fire response actions are required that are not proceduralized, the fire HRA should not take credit for them as a first approximation. Non-proceduralized recovery actions are to be credited on an as-needed basis. As the fire PRA is further developed, there may be a desire to credit non-proceduralized actions. These cases could be considered if the following requirements in Supporting Requirement HR-H2 of the ASME/ANS Standard [5] are met:

> CREDIT operator recovery actions only if, on a plant-specific basis, the following occur:
>
> *(a)* a procedure is available and operator training has included the action as part of crew's training, or justification for the omission for one or both is provided
>
> *(b)* cues (e.g., alarms) that alert the operator to the recovery action provided that procedure, training, or skill of the craft exist
>
> *(c)* attention is given to the relevant performance shaping factors provided in HR-G3 and to those discussed in this report
>
> *(d)* there is sufficient manpower to perform the action

For fire HRA, item (*b*) is especially important. It must be known that the cue will be unaffected by the fire. The following must also be known:

- There is adequate time for the operators to perform a diagnosis and the necessary tasks.
- Enough crew members are available. (In many instances, some of the operators will be assigned to the fire bridge and unable to assist.)
- The location of the fire will not prevent the operators from performing the tasks.

As with procedures, training for both control room and local actions is an important factor when assessing operator performance. As stated in NUREG-1852 [10], training supports three functions for operator performance during a fire:

- Training establishes familiarity with the fire procedures and equipment needed to perform the desired actions as well as potential conditions in an actual event.
- Training provides the level of knowledge and understanding necessary for the personnel performing the operator manual actions to be well prepared to handle departures from the expected sequence of events.
- Training gives the opportunity to personnel to practice their response without exposure to adverse conditions, enhancing confidence that they can reliably perform their duties in an actual fire event.

For actions proceduralized in the EOPs/AOPs and NOPs, operators can be considered "trained at some minimum level" to perform their desired tasks. U.S. nuclear plants have standardized requirements for training for all licensed operators on these types of procedures. Currently, there is no standardized approach to training on fire procedures among U.S. utilities. Therefore, the crew's familiarity and level of training (e.g., types of scenarios and frequency of training or classroom discussions and/or simulations) need to be evaluated on a plant-specific basis. Training on fire PRA scenarios can often offset the effects of other negative PSFs such as poor procedures, limited time available, cues and indications, and complexity.

An especially important concern is the decision of “if and when” to leave the MCR. The procedural guidance, training received, and the explicitness and clarity of the criteria for abandoning the MCR must be considered. This concern is an area of uncertainty because there may not be clear decision criteria for abandonment; it may be at the discretion of the shift supervisor. The decision to leave the MCR and the timeliness in which this decision is made can have serious ramifications. Problems leading to a higher likelihood of failure to reach safe shutdown can arise if the crew delays too long in leaving or if they leave too quickly. Decisions about how to model the decision to leave the MCR will depend on the impact of early or late abandonment. Discussions with those responsible for making the decision to abandon the MCR under various conditions and information on how they are trained and experiences they have had related to abandoning the MCR will be critical to determining appropriate HEPs. Section 4.8 provides further discussion on this subject.

4.6.4 Complexity

As discussed in Appendix B of NUREG-1792 [6], the PSF addressing complexity attempts to measure the overall complexity involved for the situation at hand and for the action itself (e.g., many steps have to be performed by the same operator in rapid succession versus one simple skill-of-the-craft action). Many other PSFs affect the overall complexity, such as the need to decipher numerous indications and alarms, the presence of many complicated steps in a procedure, or poor HMI. Nonetheless, this factor also captures “measures” such as the ambiguity associated with assessing the situation or in executing the task, the degree of mental effort or knowledge involved, whether it is a multivariable or single-variable task, whether special sequencing or coordination is required for the action to be successful (especially if it involves multiple persons in different locations), or whether the activity may require sensitive and careful manipulations by the operator. The more these measures describe an overall complex situation, the more this PSF should be identified as a negative influence. To the extent that these measures suggest a simple, straightforward, unambiguous process (or one that the crew or individual is familiar with and skilled at performing), this factor should be found to be nominal or even ideal (i.e., have a positive influence).

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 can increase. Adding to this complexity is the extent to which multiple actions must be coordinated. The number and complexity of the actions and the availability of needed communication devices should be addressed.

4.6.5 Workload, Pressure, and Stress

Although workload, pressure, and stress are often associated with complexity, the emphasis here is on the amount of work that a crew or individual has to accomplish in the available time (e.g., task load) along with their overall sense of being pressured and/or threatened in some way with respect to what they are trying to accomplish. NUREG/CR-1278 [19] provides a more detailed definition and discussion of stress and workload. High workload, time pressure, and stress are generally thought to have a negative impact on the performance of crews or individuals (particularly if the task being performed is considered complex).

However, the impact of these factors should be carefully considered in the context of the scenario and that of the other PSFs thought to be relevant. For example, in internal events HRA, if the scenario is familiar, procedures and training are very good, and the crews typically

implement their procedures well within the available time, analysts might decide that relatively high expected levels of workload and stress will not have a significant impact on performance. However, for fire HRA, if the scenario is unfamiliar, the procedures and training for the fire scenario are considered only adequate, and the time available to complete the action has been shortened because of fire, the analyst may decide that stress will have a significant impact on performance.

For local and MCR abandonment actions, there is the potential for high time pressure to reach the necessary locations and perform the appropriate actions. An important consideration in the performance of these actions is the extent to which multiple actions need to be coordinated or sequentially performed and, as discussed previously, the available time as perceived by the operators. The hazards associated with performing the actions will also be relevant.

4.6.6 Human-Machine Interface

HMI impacts operator performance differently, depending on the location of the action. In general, NUREG-1792 [6], NUREG-6850 [7], and NUREG-1852 [10] all agree that, for control room actions, the HMI will have a minimal or positive effect on human performance. This minimal effect recognizes that problematic HMIs have either been taken care of by control room design reviews and improvements or are easily worked around by the operating crew as a result of the daily familiarity of the control room boards and layout. However, any known poor HMI should be considered a negative influence for an applicable action, even in the control room. For control room actions for fire HRA, the HMIs will remain similar to those for internal events with the exception of potential impacts on instrumentation.

For local actions, the HMIs can have potentially large impacts on operator performance during a fire. Local actions may involve more varied (and not particularly human-factored) layouts and require operators to take actions in much less familiar surroundings and situations. Therefore, any problematic HMIs can be an important negative factor on operator success. For instance, if access to a valve requires the operator to climb over pipes and turn the valve with a tool while in an awkward position, or the in-field labeling of equipment is in poor condition and could lengthen the time to find the equipment, such “less ideal” HMIs could be a negative performance shaping factor. In contrast, if a review reveals no such problematic interfaces for the act(s) of interest, this influence can be considered adequate or even positive if the interface helps ensure the appropriate response in some way.

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, the fire modeling and electrical evaluation defines a *scenario* as a hot short on a control cable that causes a valve to close and drive beyond its seat, possibly making it impossible to open manually.

For control room abandonment or alternate shutdown actions, the adequacy of the remote shutdown and local panels needs to be verified. These scenarios are typically not modeled in the internal events PRA; the shutdown panel and related interfaces are plant-specific, and design reviews and improvements have not always been completed. In addition, the operators are not as familiar with the panel layout as they are in control room scenarios.

HMI PSFs need to be considered in combination with other PSFs. NUREG-1852 [10] does not explicitly discuss the HMI, but it does reference NUREG-0711, *Human Factors Engineering Program Review Model* [20], in the context of environmental conditions and communications insofar as that the HMI should support operator actions under a full range of environmental conditions and the level of communication needed to perform the task. It notes the following:

> when developing functional requirements for monitoring and control capabilities that may be provided either in the control room or locally in the plant, the following…should be considered: …communication, coordination…workload [and] feedback.

Examples cited include the following:

- Loudspeaker coverage
- Page stations
- Personnel page devices suitable for high-noise or remote areas [and] communication capability for personnel wearing protective clothing [such as] voice communication with masks

All of these factors can bear on the likely success of operator actions and need to be evaluated in assessing the time to respond.

4.6.7 Environment

If the fire does not directly impact the control room, the environmental conditions inside the control room are not usually relevant to the success of operator actions because they rarely change control room habitability. However, if the fire directly affects the MCR by smoke, the introduction of toxic gases, or fire damage and requires the control room to be abandoned, environmental conditions need to be considered as negative impacts to the crew's success.

For local actions, fires can introduce additional environmental considerations not normally experienced in response to internal events. Such factors as radiation, lighting, temperature, humidity, noise level, smoke, toxic gas, the use of water or other fire-suppression agents or chemicals–even weather for outside activities (e.g., having to go on a potentially snow-covered roof to reach the atmospheric dump valve isolation valve)—can be varied and far less than ideal. These considerations include heat, smoke, toxic gases, and different radiation exposure or contamination levels. Any or all of these considerations may adversely impact the operator actions in locations where the actions are to be taken and along access routes.

During a fire, the potential exists that the crew's ideal travel path to the action location will be blocked by the fire and lead to a delay or inability to reach the action location. Where alternative routes are possible, the demands associated with identifying such routes and any extra time associated with using the alternative routes should be factored into the analysis. Pursuant to NUREG/CR-6850 [7], if the action is required to be performed in the same location as the fire, the action should not be credited in the fire PRA.

4.6.8 Special Equipment

Because of varying environmental conditions during a fire, the crew may require the use of special equipment. These items, identified in NUREG-1852 [10] as *portable equipment*, can include keys, ladders, hoses, flashlights, clothing to enter high radiation areas, and fire special

protective clothing and SCBA. The accessibility of these tools needs to be checked to ensure that they can be located and would be accessible during a fire. Furthermore, the level of familiarity and training on these special tools needs to be assessed. Equipment tends to be more important for the success of local fire actions than control room actions.

A large fire may cause electric security systems to fail locked. In these cases, the operators will need to use keys for access to certain locations. If the operators do not normally carry keys, additional time will need to be considered for locating keys and/or obtaining access to locked areas. Operator interviews are useful in understanding how operators can obtain access to locked areas.

Abandoning the MCR might also require the donning of protective gear or SCBA. The hindrance of the special clothing on the operators' actions needs to be accounted for.

4.6.9 Special Fitness Needs

According to NUREG/CR-6850 [7], the fire and its effects could prompt the need to consider actions not previously considered under internal events or changes to how previously considered actions are performed. For these reasons, the HRA analyst should verify that unique fitness needs are not introduced. Examples of unique fitness needs include the following:

- Having to climb up or over equipment to reach a device because the fire has caused the ideal travel path to be blocked
- Needing to move and connect hoses, especially if using a heavy or awkward tool
- Using SCBA, which can be physically demanding and hinder communication (as discussed in the next subsection)

4.6.10 Crew Communications, Staffing, and Dynamics

4.6.10.1 Crew Dynamics

Crew/team dynamics and crew characteristics are essential to understanding how and where the early responses to an event occur and the overall strategy for dealing with the event as it develops. In particular, the way in which the procedures are written and what is (or is not) emphasized in training can affect overall crew performance. The overall strategy may be related to an organizational or administrative influence, which can cause systematic and nearly homogeneous biases and attitudes in most or all crews. A review of team dynamics typically includes the following, as described in Appendix B of NUREG-1792 [6]:

- Are independent actions encouraged or discouraged among crew members? Allowing independent actions may shorten response time but could cause inappropriate actions to go unnoticed until much later in the scenario.
- Are there common biases or "informal rules?" For example, is there a reluctance to perform certain acts, is there an overall philosophy to protect equipment or run it to destruction if necessary, or are there informal rules regarding the way in which procedural steps are interpreted?

- Are periodic status checks performed (or not) by most crews so that everyone has a chance to "get on the same page" and allow for checking on what has been performed to ensure that the desired activities have taken place? In general, are good communication strategies used to help ensure that everyone stays informed?
- Is the overall approach of most crews to aggressively respond to the event, including taking allowed shortcuts through the procedural steps (which will shorten response times), or are typical responses slow and methodical (a "we trust the procedures" type of attitude)—slowing down response times but making it less likely to make mistakes? In general, deciding whether the crew characteristics have a positive or negative effect will be contingent on the scenario being examined. For example, a particular bias may be positive for some scenarios but not for others.

For fire HRA, the typical internal events crew dynamics may change as a result of responding to a fire and need to be reconsidered. For instance, the fire may create new or unique fire-related responsibilities that have to be handled by a crew member. The use of plant status discussions by the crew may be delayed or performed less frequently, allowing fewer opportunities to recover from previous mistakes. Such differences may best be determined by talk-throughs with operations staff as well as observing simulated responses of fire scenarios. The main goal of such an analysis is to determine whether any particular crew characteristics or team dynamics could impact a given accident scenario and human action being addressed. Certain characteristics may be acceptable for most scenarios but could cause problems in others.

For the purpose of HRA in the context of PRA, the review of crew dynamics is typically limited to understanding the expected crew response based on plant-specific training. Within a given plant, all crews are typically assumed to respond similarly, and there is no expected variation among crews for the same scenario.

4.6.10.2 Crew Availability

Fire can introduce additional demands for staffing resources beyond what are typically assumed for handling internal events. These demands can take the form of using two procedures in parallel or needing to use and coordinate with additional personnel to perform certain local (ex-CR) actions and with the fire brigade and/or local fire department personnel. According to Appendix B of NUREG-1792 [6], for control room actions, the availability of staff is generally not an important consideration for internal events PRA because plants are supposed to maintain an assigned minimum crew with the appropriate qualified staff available in or near the control room. One of the key assumptions in NUREG/CR-6850 [7] is that even if one or more MCR persons is used to assist in ex-control room activities such as aiding the fire brigade, the minimum allowable number of plant operators remains available.

For other ex-control room local actions, crew availability of staff can be an important consideration particularly depending on the number and locations of the necessary actions, the overall complexity of the actions that must be taken, and the time available to take and required to perform the actions.

For MCR abandonment actions or alternate shutdown actions, the crew will be dispersed to various alternate shutdown panels and controls. This dispersal requires additional coordination among all crew members. It must therefore be ensured that adequate control room members are necessary to fulfill the needs of proper shutdown actions from alternate and remote shutdown panels.

4.6.10.3 Communication

For both internal events and fire HRA control room actions, communication among crew members should be verified. Typically, an established strategy will be in place for communicating within the control room that ensures that directives are not easily misunderstood. Do crew members avoid the use of double negatives? It is expected that communication will not be a problem; however, any potential communication problems (such as having to talk while wearing SCBA in the control room in a minor fire) should be accounted for if they exist.

For local actions, communication may be much more important because of the possibility of a less-than-ideal environment or situation. The way in which equipment faults caused by the fire could affect the ability of operators to communicate as necessary to perform the desired act(s) should be understood. For instance, having to set up equipment and talk over significant background noise and possibly having to repeat oneself many times should be considerations, even if only as possible “time sinks” for the time to perform the act. For fire conditions, the communication devices necessary to carry out the desired actions may or may not be available—for example, the plant loudspeaker coverage may be disabled because of the fire. In addition, the operators’ level of familiarity and training to use any special communication devices needs to be assessed. There is also the potential that the crew will need SCBA, and communicating through these devices can be difficult.

Following MCR abandonment, the location of remote and alternate shutdown panels and the required related actions may be in a variety of places. Therefore, the ability to communicate from different places should be considered and addressed. Furthermore, if SCBA is required to be worn, the apparatus might interfere with clarity in communications among team members. The ability of operators to communicate with one another during the initiation and execution of the tasks and after their completion is critical.

Communication can be directly related to other PSFs such as environmental conditions, timing, complexity, and crew discussions about faulty indications.

4.7 Review of Relevant Experiences

To gain a better understanding of the plant response following an event, the fire HRA analyst should consider reviewing relevant experiences. The analyst should look at both plant-specific events and industry-wide incidents to populate these reviews. Typically, the experience review is focused on events of a particular type with an emphasis on the associated human performance. In this way, the analyst can truly evaluate the effect of such incidents and gain insight into the context in which accidents can occur. Although these reviews are helpful at the beginning of a HRA, they are particularly relevant to a detailed HRA in which more specifics are necessary.

The search for relevant historical experiences will usually focus on a specific type or class of events (e.g., a particular type of initiating event such as a fire or small LOCA). When gathering industry-wide experiences, the analyst may want to look at NRC Information Notices or similar types of information; these notices sometimes include summaries of example events along with a discussion of the associated problems and surrounding context.

Conducting a historical review of plant-specific and industry-wide experiences exposes the analyst to a variety of plant conditions and progressions (including timing issues) that should be considered in the HRA. Furthermore, the review may reveal potential influences on operator

performance (e.g., plant conditions and associated gaps in performance shaping factors such as procedures or training) and challenging conditions or situations the operators might encounter. Operator performance during unusual plant conditions may reveal deficiencies in the human-centered factors (e.g., PSFs) that lead the operators to make errors in responding to the situation. The study of these situations helps the analyst identify the context of the incident, especially the plant conditions, the significant PSFs, and the dependencies that set up the operators for failure.

Finally, plant-specific sensitivities or tendencies may have been influenced by a previous event and may need to be accounted for in the fire HRA in general and the dependency analysis in particular. These occurrences may have been affected by plant policies and/or the informal rules that operators follow and would therefore impact the HEP. To this end—and as a further benefit to reviewing previous events—the discussion among PRA team members and operations staff is often more productive if the specifics of a historical event can be used as an illustrative example.

4.8 Qualitative Analysis Associated with MCR Abandonment Actions

Although several previous sections on PSFs address specific issues that need to be evaluated when performing the qualitative analysis associated with MCR abandonment, a key aspect that may need additional guidance concerns the decision of "if and when" to leave the MCR. There are two basic reasons for MCR abandonment in the context of a fire: 1) an uninhabitable environment in the MCR because of fire effects (e.g., smoke, flames, or toxic gases) and 2) plant monitoring **and** control cannot be achieved within the MCR because of an inability to control key safe shutdown equipment such as might occur following a cable spreading room fire.

As discussed next, certain timing concerns need to be addressed along with PSFs. For example, the time available for safe shutdown actions will be reduced by the time taken to decide to abandon the MCR and perform actions to switch control to an alternate shutdown location. Some plants (e.g., those that use the SISBO strategy) may have additional timing considerations to address. In such cases, there may be a timing requirement involved with switching plant control from the MCR to the alternate shutdown panel to maintain electrical independence between the two locations. If so, it would be appropriate to explicitly model an HFE that represents the failure of switchover to the alternate shutdown panel using that timing requirement and including any failures related to the decision to abandon the MCR.

4.8.1 Habitability

For the habitability case, to establish when MCR abandonment might be expected to occur, it is suggested that at least one of the following criteria from NUREG/CR-6850 [7] be satisfied:

- The heat flux at 6 ft (1.8 m) above the floor exceeds 1 kW/m^2 (relative short exposure). This can be considered the minimum heat flux for pain to skin. Approximating radiation from the smoke layer as $q_r'' = \sigma * T_{sl}^4$, a smoke layer of around 95°C (200°F) could generate such heat flux.
- The smoke layer descends below 6 ft (1.8 m) from the floor, and the optical density of the smoke is less than 3 m^{-1}. With such optical density, a light-reflecting object would not be seen if it is more than 0.4 m away. A light-emitting object will not be seen if it is more than 1 m away.
- A fire inside the main control board damaging internal targets 7 ft (2.13 m) apart.

If any of these criteria would be met based on the expected evolution of the fire scenario, subsequent actions will need to be quantified as MCR abandonment or alternate shutdown actions. The time relative to the start of the fire at which these criteria would be expected to be reached will provide input to estimating the time available to perform safe shutdown actions after MCR abandonment.

4.8.2 Ability to Control the Plant

When habitability is not an issue, it is reasonable to expect that the MCR would not be completely abandoned.[8] For these cases, the HRA should focus on how the crew would need to respond to the scenario given the specific fire effects. In particular, for a given fire and its expected effects on equipment, analysts will need to determine whether the crews would need to switch command and control to an ex-CR location (alternate shutdown) or whether it would be possible to direct the actions and to control the plant from the MCR. This determination should be based on interviews with plant operators and trainers and an examination of the plant fire procedures, given the expected fire effects. If it is decided that the MCR would not need to be abandoned, timing considerations for modeled actions would not need to be changed unless it was thought that delays might occur as a result of the crew considering the potential need to abandon the MCR.

However, if the effects of the fire could be significant enough that relocating command and control to outside the MCR (e.g., switching to an alternate shutdown panel [ASP], remote shutdown panel [RSP], or an alternate shutdown strategy) would probably be required (e.g., large fire in the cable spreading room), analysts will need to estimate when switchover would be likely to occur. Obviously, this may not be a simple estimate, but it will be important for determining how much time will be available for post-abandonment actions. However, there may not be clear decision criteria for abandonment. Rather, it may be at the discretion of the shift supervisor. Nevertheless, because the decision to leave the MCR—and the timeliness with which this decision is made—can have serious ramifications for reaching safe shutdown, analysts will need to provide as reasonable an estimate as possible for the time at which the decision to abandon would be made. Although the decision to abandon will depend to some extent on the impact of early or late abandonment for a given plant, in general, unless information to the contrary is obtained through interviews with plant personnel, analysts should assume that operating crews will abandon as needed to successfully control the plant.

Discussions with those responsible for making the decision to abandon the MCR under various conditions along with information on how they are trained and experiences they have had related to abandoning the MCR will be critical to obtaining reasonable estimates of the timing and appropriate HEPs. For example, the timing of training exercises related to the performance of sections or the entirety of MCR abandonment procedures may be available and can provide input to time estimates for the fire HRA MCR abandonment analysis. In addition, individual tasks performed as part of the safe shutdown process may be consistent with HFEs already modeled in the fire PRA and can be applied to the abandonment analysis—but with consideration for where the task is taking place and whether the timing and actions are still applicable.

[8] Analysts may want to determine if there are exceptions to this expectation or if there are plant-specific reasons why such an assumption would not be valid.

4.9 Qualitative Analysis Associated with Preemptive Procedures

Revision 2 to Regulatory Guide 1.189, *Fire Protection for Nuclear Power Plants* [21], describes certain assumptions under its stated fire protection program goals/objectives. One such assumption (on page 17 of that document) discusses a special case involving LOOP/station blackout:

> Several operating plant licensees have alternative methodologies that rely on intentional disconnection of alternating current (AC) power to specific equipment or to the entire plant as a means to achieve safe shutdown after a fire. The purpose of these self-induced station blackouts (SISBOs) is to eliminate potential spurious actuations that could prevent safe shutdown and allow manual control of required equipment. Some licensees have procedures that cause a SISBO condition to be created as a result of fire effects (e.g., procedures that direct operators to manually trip the credited safe-shutdown emergency diesel generator (EDG) in the event of fire damage to circuits of vital EDG support systems). The acceptability of safe-shutdown procedures that voluntarily enter, or otherwise create, a SISBO condition is determined on a case-by-case basis.
>
> The ability to cope with SISBO as part of the post-fire safe-shutdown methodology depends on such issues as time-line logic; assumptions and bases for plant and operator response relative to component realignment; the ability of plant operators to monitor and control plant parameters and align plant components before, during, and after SISBO control room evacuation and abandonment; and the practicality and reliability of EDG start and load (and restart, if applicable) under postfire safe-shutdown SISBO conditions.
>
> The risk of self-imposed SISBO may exceed the actual risk posed by the fire, and the licensee should consider the risk carefully when evaluating the plant safe-shutdown design and procedures. A plant typically uses this approach to avoid or minimize the number of potential spurious operations from unprotected cables and the need for OMAs after a fire. However, acceptable operator manual actions that are implemented in accordance with Regulatory Position 5.3.1.3 and [NUREG-1852] may present a lower risk than the SISBO approach.

NUREG-1852 [10] does not specifically address SISBO situations but rather provides a set of "criteria and associated technical bases for evaluating the feasibility and reliability of fire operator manual actions." Examples of these technical bases are adequate time available to implement actions, environmental factors (e.g., radiation, temperature, and smoke), and procedures and training.

Regulatory Position 5.3.1.3 of Revision 2 to Regulatory Guide 1.189 states:

> When one of the redundant safe-shutdown trains in a fire area is maintained free of fire damage by one of the means specified in Regulatory Position 5.3.1.1 (Protection for the Safe Shutdown Success Path), then the use of operator manual actions may be credited with mitigating fire-induced operation or maloperation of components that are not part of the protected success path. The crediting of operator manual actions should be in accordance with the licensee's FPP and license condition. Operator manual actions may also be credited when an alternative or dedicated shutdown capability is provided as described in Position 5.4.

> All postfire operator manual actions should be feasible and reliable. [NUREG-1852] provides the technical bases in the form of criteria and technical guidance that may be used to demonstrate that operator manual actions are feasible and can be performed reliably under a wide range of plant conditions that an operator might encounter during a fire. The use of feasible and reliable manual actions alone may not be sufficient to address all levels of defense in depth. Therefore, fire prevention, detection, and suppression should be considered, in addition to the feasibility and reliability of operator manual actions.

In the excerpt above, the phrase "crediting of operator manual actions should be in accordance with the licensee's FPP and license condition" means that if the plant's license condition is Appendix R, then required protection of redundant systems located in the same fire area according to Appendix R, Sections III.G.1 or III.G.2, must be provided. However, if the plant's license condition is NFPA 805, then it must be shown that either the redundant systems are protected, or the electrical faults in question are inconsequential based on fire modeling or risk significance.

This essentially means that an analysis of SISBO or single-circuit fault clearance strategies should be conducted as part of a safe shutdown analysis to ensure that Appendix R (or NFPA 805) safe shutdown system protection requirements are met and that OMAs are considered feasible and reliable according to the criteria in NUREG-1852.

Within the U.S. nuclear industry, there is a range of fault clearance scenarios—from small single circuits, to massive safety bus clearing and power restoration, to clearing a limited portion of the bus. Each case involves different procedures for when a bus clearing would be performed. For example, one part of the bus may be located in a fire zone unrelated to the selected train of equipment, and the operators would therefore want to isolate that bus because they are protecting a train. For plants in which uncertainty exists about equipment wiring schemes, the preference might be to clear out and start over to ensure that they do not have a short or ground that would cause problems on the preferred bus. However, because each plant has its own strategy and procedure for this process, generalizations are difficult to make. Typically, these strategies are implemented through the use of fire location-specific, and often complicated, procedures.

This section offers considerations for evaluating HRA issues for NPPs that use fire procedures to clear electrical faults associated with fire-induced spurious events. Because plant-specific variations and explicit guidance for performing fire HRA cannot be provided, this section instead includes some general recommendations for the way in which fire HRA tasks might need to be performed differently to address the HRA issues of concern for fault clearance strategies.

Section 3.3 provides discussion on the identification and definition of actions using SISBO procedures. The qualitative assessment portion of the fault clearance scenario evaluation should be performed in a manner consistent with the discussions in this section as well as consideration for the unique considerations discussed next.

One process that has been implemented for SISBO evaluation is to qualitatively model the human response to a fire as a chain of elements. The chain begins with a cue and ends in either a success or failure event as follows:

Cue |→ Error → Failure of Recovery → Failure Event

|→ Success → New Cue or Success Event

This structure facilitates the evaluation of success and failure states needed to model the procedure selection between EOPs and fire procedures, allowing the analyst to focus on the HFEs that could fail a safety function required to prevent core damage. This process can assist in grouping the analysis of many steps in the procedures. For the SISBO condition, this involves two major steps: 1) clearing the bus or circuit by removing power and 2) restoring the section of the bus or circuit needed to operate a selected safe shutdown cooling configuration. Within each main step are many opportunities to define HFEs from the procedures. In addition, the workload from these additional steps should be considered in qualitatively evaluating each HFE.

The following PSFs could be expected to be important for the fault clearance scenarios:

- Complicated procedures and potential interaction among EOPs, AOPs, and fire procedures, particularly the consideration of hesitancy by operators to enter procedures that might require SISBO
- Difficulty in communications between control room and field operators (e.g., when the latter must use SCBA)
- Coordination of multiple actions
- Field actions in a variety of locations (possibly with different environmental conditions)

Other special considerations for the detailed modeling of fire-related SISBO and single-fault clearing scenarios are the following:

- Detailed modeling is required for unscreened fire zones for which operators are called upon to use additional attachments or parts in fire procedures (or entry procedures to the fire procedures) have the potential for a loss of safety functions resulting from errors in applying these modified parts and added attachments.
- Detailed modeling is required for conditions prior to entering the fire procedures where hot shorts have occurred as a result of the fire. This causes valves and other components to be in undesired positions, and the operators are not able to make appropriate realignments using EOPs.

Top events identified in the internal events PRA model are often used to define the initial system-level operator actions based on the success criteria for the equipment. Additional event tree analysis may be needed to construct a logic model that links realigned functional safety elements to the HEP calculation.

The HEPs for HFEs associated with staying in the EOPs are, in many cases, lower than those for implementing the fire procedures. This is an operator decision that impacts whether the clearing and restoring actions are carried out. The following should be considered:

1. The choice of procedures to use can significantly impact the HEP for the fire zone.
2. One assumption for the initial modeling of the HEP is that, given that the fire was not put out quickly, the operators always go directly to the fire procedures.
3. The use of fire procedures is delayed until the operators cannot control the plant.

4. A detailed decision model is needed to evaluate the error potential associated with decisions that the operators could make to enter (or not enter) the fire procedures from the EOPs.
5. Data for implementing this model can be obtained through operator interviews. An interview form can be used to record the results.

If abnormal conditions arise as a result of independent equipment failures prior to fire procedures implementation, only equipment that is repositioned or verified within the fire procedures steps is recovered. Cues for equipment failures outside the fire procedures or after application of the fire procedures are assumed to be unobserved and not recovered in the model contributing to the HEP value.

After the safety function has been identified for one or more actions in a portion of the procedure, the likelihood of failure for that procedure element is based on the probability that one or more steps is omitted or performed incorrectly. The approximate time window for success associated with the scenario is based on the deterministic safe shutdown assessment documented in the fire hazards report.

The screening method discussed in Section 5.1 supports the assignment of screening values by addressing the conditions that can influence crew performance during fires, ensuring that the time available to perform the necessary action is appropriately considered (given the other ongoing activities in the accident sequence) and that potential dependencies among HFEs modeled in a given accident sequence are addressed.

The Set 3 screening criteria discussed in section 5.1.1.3 address new HFEs added to the fire PRA or prior internal events PRA HFEs needing to be significantly altered or modified in Step 1 of this procedure because of fire conditions. Set 3 is therefore considered to be the screening criteria applicable to the fault clearance scenario. Depending on the Set 3 criteria, a screening value of either 1.0 or 0.1 may be used to determine the initial impact and the need for scoping or detailed modeling.

It is expected that HFEs associated with the bus clearing strategy scenarios will be quantified using detailed HRA quantification. For this type of situation, using the scoping trees provided in Section 5 of this report is not recommended because of the complexities, crew interactions, and various PSFs involved in these scenarios. The scoping trees were not constructed to address these bus clearing and reconfiguring actions. Detailed HRA quantification will be needed for any HFEs that survive screening quantification.

4.10 Qualitative Analysis Associated with Operator Response to Spurious Operations

One of the unique aspects of performing a fire PRA is the need to address the effects of fire damage on cables and the resulting impact on components and instrumentation. These effects can have a direct effect on the fire PRA, such as a loss of a safe shutdown component, or an indirect impact, such as causing a complex event or a distraction. An example of the fire increasing complexity is a situation in which the fire affects the power supply to valves in a system but not the pumps, so that the system may initially appear to be operating normally. An example of the fire having an impact that may cause a distraction is a fire that affects balance-of-plant components important to power generation, such as the turbine. As summarized in the discussion

in Section 2.5 and Table 2-2, many fire PRA tasks (including component selection, MSO expert panel, fire-induced risk model, and circuit analysis) are involved in this effort to determine such damage and how to represent these effects in the HRA/PRA.

This report, NUREG/CR-6850 [7], and the fire PRA requirements in the PRA Standard [5] have captured and attempted to advance the current state of the art with respect to the representation of fire-damaged cables in fire HRA/PRA, particularly in the following areas:

- The spurious operation of equipment and associated control functions modeled in the PRA
- The spurious operation of instruments or alarms needed by the operators to achieve safe shutdown

In the area of fire HRA, the state of the art has been advanced by addressing potential spurious indications that could mislead operators into taking actions (i.e., errors of commission) resulting in a damage state with additional components failed (beyond those directly impacted by fire). Table 2-2 identifies this impact on the fire HRA task, and Section 3.4 provides guidance on how to identify such opportunities through procedure reviews. The guidance in this report has focused on a single spurious instrument or alarm that, by itself, is a cue for an inappropriate action (consistent with Capability Category II). Capability Category III of the fire PRA Standard does, however, address the possibility of more than one spurious indication or alarm (e.g., a combinations of indications) resulting in an inappropriate operator action. When identified, these cases can also be addressed using the scoping and detailed quantification approaches provided in this report.

Real-world events (e.g., Browns Ferry [22–26] and Narora [27]) have demonstrated that multiple spurious operations can occur, even beyond those conventionally modeled in fire HRA/PRA. The impacts of these spurious operations range from instrumentation failure to spurious alarms to spurious actuations of components. Although fire HRA/PRA addresses multiple spurious operations to some extent, it does not explicitly identify all of the potential spurious operations that could occur. In general, the fire HRA/PRA addresses only spurious operations of the equipment modeled in the PRA or spurious instruments or alarms that are cues for operator actions of interest in the fire PRA. In principle, many other potential spurious operations may occur for a particular fire scenario. However, these may not have been identified because they are not directly relevant to the safe shutdown path and their impact on operators is uncertain.

Based on accounts of events such as Browns Ferry and Narora, operational experience data show that it is possible for operators to become confused or distracted by spurious instruments or alarms. In theory, operators should be focused only on the safe shutdown paths (particularly the available train[s] unaffected by the fire), associated equipment, and instruments and alarms as directed by the applicable procedures. However, in a complicated scenario such as a fire, maintaining this focus might be difficult. In addition, good reasons might exist for the operators to have a wider scope of attention (e.g., secondary-side systems or equipment that is commonly important during normal operations and systems or equipment of recent concern as a result of current plant configurations and preexisting conditions).

Unfortunately, because of the variety of potential fire scenarios and plant-specific configurations and conditions, there is no generic and predictive way to identify which additional spurious instruments or alarms might be sufficiently distracting or delaying to result in a human failure event (e.g., system or plant function failures). However, the following potential information might help:

- If the fire PRA can identify that there are **no** other cables in a particular fire location, the fire HRA analyst can assume that distractions from other spurious indications or alarms do not need to be considered.
- If fire procedures identify not only indications and alarms in a list of protected equipment but **also** identify a list of possibly affected equipment (including all potentially affected indications and alarms), the potential for operator distraction by such indications and alarms can be assumed to be significantly reduced (although not entirely eliminated).

In most cases, only a limited set of cables is traced. It is therefore likely that the fire PRA will not be able to identify many areas in which no cables are affected. Because it is also likely that the HRA analyst cannot eliminate the possibility of operator distraction caused by spurious indications or alarms that have not been explicitly identified, it would be good practice to somehow reflect this possibility in HRA quantification. Unfortunately, the accident record for such real-world fire events is too small—even coupled with theoretical support from psychology and cognitive and behavioral sciences—to support the development of a generic and prescriptive approach. In addition, the scope of fire contexts is broad (more so than for internal events PRA), resulting in part from the variety of possible fire locations, fire growth potential, plant-specific differences in spatial design, fire mitigation equipment, and so on.

Therefore, except for cases in which either the fire PRA information eliminates the possibility of spurious indications and alarms or fire procedures "tip off" the operator to potential spurious actuations of specifically identified indications and alarms, the HRA analyst must recognize that the potential impacts on the operator could range from virtually no effect to significant effect (i.e., failure of an HFE modeled in the fire PRA). Even if further fire PRA refinements were performed, this uncertainty may still exist unless some justification can be developed to support the assumption that the operator will ignore these additional spurious indications or alarms. Consequently, the HRA can be considered to be at a sort of "dead end" because no existing HRA method (including the fire HRA quantification methods described in this report) is capable of addressing such cases directly, even if more information is made available.

The development of an explicit quantification approach to address potentially distracting spurious indications and alarms has not been included in the scope of this report. Instead, one of the following strategies could be implemented:

- Identify (i.e., flag) plant areas that fail instrumentation used to respond to the fire-induced initiating events, and/or represent the impact of the failed instrumentation by modifying the HEPs for associated fire HFEs (either in the base case quantification of that area or in a sensitivity case). For example, for areas in a PWR that fail steam generator level indication, the analyst may quantify a revised HEP for manual control of feedwater—using the partial instrumentation cases in the scoping and EPRI methods as part of the base case fire PRA modeling of that area—or may revise the HEP in a sensitivity study.

- Identify (flag) plant areas that fail important components in such a way that would divert the operator's attention from the safe shutdown train, for example, a PORV spuriously opening or failure of components in the non-credited train or in an important balance-of-plant system.

Sensitivity studies could be conducted to identify whether the cable failures have little (or no) effect, a significant effect, or perhaps a moderate effect. Effects might be represented and evaluated simply as different "flavors" of HEPs for the same HFE. Alternatively, the timing of associated operator actions might be varied to assess the way in which additional delays (resulting from the distracting effects of additional spurious indications and alarms) translate into altered HEPs. Such simple approaches could be applied to HFEs included and quantified in the fire PRA with any of the fire HRA quantification approaches presented in this report.

However, given that explicit and prescriptive guidance is not given in this report, this issue represents another area that could benefit from future research and development in fire HRA/PRA.

4.11 Reviews with Plant Operations

The fire HRA analyst typically conducts several interviews of plant operations personnel to confirm an understanding of the plant response and help ensure that the HRA reflects the "as-built, as-operated" plant.

The first interview session is typically conducted early in the HRA development. In this first session, the HRA analyst should confirm with plant operational personnel the general organizational factors affecting fire HFEs such as crew staffing, procedural hierarchy, and communications protocols. Discussion with operators can often reveal that there are policies and/or "informal rules" among operators about which even the training staff may be unaware.

Understanding how and when the fire procedures are implemented can drive the HEP results. Operator interviews have shown that the use of the fire procedures can vary widely among plants and that sometimes the use of the procedures is at the discretion of the shift supervisor. At some plants, the fire procedures are implemented in parallel with the EOPs; at others, they are implemented after completion of the EOPs—at still other plants, they are combined with EOPs. When and how the procedures are implemented will affect PSFs such as timing and crew availability and workload. Other informal rules can include departing from the EOPs when the diagnosis is clear to the operators or anticipating alarms and acting before the minimum time necessary.

In addition, the way in which the crew will interact with the fire brigade should be confirmed. The crew's tasks during a fire may be varied; any additional tasks would lead to an increased workload. It is important to confirm that a minimum set of operators and staff is available to complete the actions modeled.

Additional sessions are conducted after each HFE has been quantified, such as performing additional operator interviews to review and confirm the modeling to date. In these operator interviews, plant-specific data are collected through plant walk-downs, simulator observations, and/or operator talk-throughs. These interviews "tune" the fire HRA model to the accident scenario being modeled. The HRA analyst must know what is in the fire PRA model, what is in the procedures, and what the operator is actually doing (or concerned with) for the fire HRA model to be most representative of plant-specific behavior. Guidance on the performance of talk-throughs and walk-throughs is provided next. The additional sessions of operator interviews are repeated as the fire PRA model is developed and stabilized.

Operator walk-throughs and talk-throughs provide timing information in addition to insights in understanding the plant response. Specifically, the combined ASME/ANS PRA Standard in Supporting Requirement HR-G5 discusses basing the "required time to complete actions on action time measurements in either walk-throughs or talk-throughs of the procedures or simulator observations" [5].

The talk-through and walk-through processes are activities that seek to determine the likely outcome(s) of a situation based on starting conditions and the effects of decisions made—the former through structured discussions and the latter through enactments under the most realistic conditions possible. The fire HRA information gathering process is therefore likely to involve talk-throughs and walk-throughs with operations and training personnel, including photo-documentation of locations to be accessed, equipment to be actuated, and tools to be used.

4.11.1 Talk-Throughs

The following are important aspects of performing talk-throughs:

1. Operators, trainers, and other knowledgeable plant staff should be involved to the extent possible. Ideally, those who would have to perform the action (or set of actions) should be interviewed. More than one expert should be involved if possible, that is, to get more than one opinion about the timing for the actions being examined in obtaining the estimate.
2. Do a thorough task breakdown so that the necessary actions and their locations are clear.
3. Use the applicable procedures to identify the need for the actions and the procedure steps that will guide the execution of the actions in evaluating and determining the time requirements. Consider how the procedures will be used (e.g., followed carefully in a step-by-step way or used more generally) in estimating time requirements for the actions.
4. Determine the key indicators for the action and how soon the operators would be expected to detect and begin responding to the cues given the fire scenario. Include any expected delays in detecting and responding to the cues in estimating crew response time for the actions.
5. Consider the list of feasibility assessment factors discussed previously that could influence performance in estimating the likely time requirements for a given action or set of actions.
6. The team participating in the talk-through should have a thorough discussion of the tasks to be performed and the likely impacts on performance before estimating the time required.
7. An expert elicitation process such as that described in the ATHEANA User's Guide (NUREG-1880 [3]) could also be used in estimating the time requirements for the actions being assessed.

4.11.2 Walk-Throughs

It will not always be possible to conduct all of the subtasks and simulate all of the conditions that might occur during a fire that could affect the time to diagnose and perform an action. Even for MCR actions, it will be difficult to simulate the effects of a fire (either inside or outside the MCR) and how those effects might impact the crews' ability to respond to an accident scenario. Therefore, some estimates about aspects of the time required, given the expected conditions, will have to be based on judgment. If the demands of the task and the time to complete the actions must be based on the judgment of plant personnel, a process should be used to help ensure that

the estimates are reasonable (e.g., obtain multiple independent judgments). It is primarily important that a reasonable effort be made in conducting a realistic evaluation and that knowledgeable plant staff are used to provide information and estimates to adequately simulate the actual plant conditions during the walk-through.

Ideally, to get as realistic an estimate of the time required to perform the actions as possible, several crews would be used in conducting the walk-throughs. However, because this may not always be possible, at least one randomly selected, established crew should participate.

Given the range of factors that can influence the time to complete an action, to the extent possible, the conditions under which the diagnosis and execution will have to occur should be clearly discussed, evaluated, and documented during the structured interview or walk-through to determine the reliability of situations or factors in the fire context. For example, the operators may need to recover from or respond to difficulties such as problems with instruments or other equipment (e.g., locked doors or an erratic communication device). Such difficulties can and sometimes do happen and represent an uncertainty in how long it will take to perform an action.

Environmental and other effects might exist that are not easily simulated in a walk-through, such as those cited in Section 4.6.7 regarding environmental factors that could influence operator performance. These effects may not all be simulated in a walk-through but should be considered possible and discussed with operations in determining the time it may take to perform the manual action in a real situation. For example:

- The walk-through might be limited in its ability to account for (or envelop) all possible fire locations in which actions are needed and for all of the different travel paths and distances to where the actions are to be performed. A similar limitation is that the location or activities of needed plant personnel when the fire starts could delay their participation in executing the OMAs (e.g., they may typically be in a location that is on the opposite side of the plant for a postulated fire location and/or may need to restore certain equipment before being able to participate, such as routinely doing maintenance). The intent is not to address temporary or infrequent situations but to account for those that are typical and may impact the timing of the action.
- It may not be possible to execute relevant actions during the walk-through because of normal plant status and/or safety considerations while at power (e.g., operators cannot actually operate the valve using the handwheel; they can only “talk-through” doing so).

4.12 References

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5
QUANTIFICATION

This report describes three types of approaches for quantifying the HFEs identified in the fire PRA models. These methods offer a stepped approach, progressing from a simpler screening method to more detailed methods. Although the stages are presented sequentially, it is not intended that an analyst progress through them sequentially or use all of the methods.

Before quantifying an HFE, the analyst must have applied the criteria discussed in Section 4.3 for assessing the feasibility of the operator action(s) associated with that HFE. Although the feasibility assessment process begins at the identification and definition stage and is a key part of the initial qualitative analysis, new information may be available during the quantification process that would require the feasibility to be reassessed. Therefore, feasibility assessment is a continuous action step throughout the fire HRA.

For each HFE requiring quantification, the analyst has the following options for quantification:

1. Screening HRA similar to that presented in NUREG/CR-6850 [1].
2. A new scoping fire HRA quantification method, which is introduced in this report.
3. Two detailed HRA quantification approaches modified for application in fire PRAs.

The first quantification method described (see Section 5.1) is a screening analysis. The screening methodology assigns quantitative screening values to the HFEs modeled in the fire PRA by addressing the unique conditions created by fires. To determine appropriate HEPs, a given HFE must be matched to a set of criteria. The HEPs assigned in this manner are conservative and may not be acceptable as a final HEP for a given HFE (i.e., a more realistic HEP is needed). This initial assignment of HEPs is useful in identifying HFEs that may be risk-significant events or most important to overall risk results. In addition, because the screening approach assigns a screening value of 1.0 for alternate shutdown actions (including MCR abandonment as a result of habitability), a possible next step and conservative approach (similar to an approach presented in NUREG/CR-6850) is provided at the end of the screening section. This approach allows the assignment of a single overall failure probability value (e.g., 0.1) to represent the failure of reaching safe shutdown using alternate means (including MCR abandonment) if certain minimal criteria are met.

An alternative approach—the scoping method—is presented to alleviate some of the conservatism of the screening approach and may be used in lieu of the screening approach if potentially less conservative initial HEPs are desired. The scoping fire HRA approach is a simplified quantification approach developed specifically for this report that addresses fire-specific aspects of operator performance. The scoping analysis outlined in Section 5.2 uses decision-tree logic and descriptive text to guide the analyst to the appropriate HEP value.

Although it has similarities to a screening approach, the scoping quantification process requires a somewhat more detailed analysis of the fire PRA scenarios and the associated fire context as

well as a good understanding of several factors likely to influence the behavior of the operators in the fire scenario. Given such an analysis, it is expected that the flowcharts provided can be used to perform quantification for many of the HFEs being modeled. However, it is expected that some actions will not be able to meet some of the criteria for any of a number of reasons (and result in an HEP of 1.0). Furthermore, the HEPs developed using this method may be conservative compared to those that could be developed using one of the two detailed HRA approaches also described in this report.

In general, scoping will produce less conservative results than those produced by the screening method; this is commensurate with the fact that scoping also generally requires a somewhat more extensive qualitative analysis. There are, however, some cases in which screening might yield lower HEPs than scoping. For certain situations, the screening method allows the use of the internal events PRA HEP. Many of these HEPs are based on a prior detailed analysis, producing a lower HEP than is obtainable using the scoping method.

For cases in which the scoping approach cannot be used or a more detailed and possibly less conservative analysis is desired (e.g., for risk-significant events identified for Capability Category II as defined in ASME/ANS Requirement HR-G2 [2]), analysts have the option of performing a detailed analysis using either of the following:

- The EPRI HRA approach [3] presented in Appendix B of this report
- The ATHEANA HRA method [4, 5] presented in Appendix C

Section 5.3 provides additional discussion regarding detailed fire HRA. Another alternative would be for the analyst to decide not to take credit for the action and assign an HEP of 1.0.

5.1 Screening HRA Quantification

Section 12 of NUREG/CR-6850 [1] provides guidance for assigning initial screening HEPs as an aid in simplifying and refining the fire PRA model to focus analysis resources on risk-significant fire scenarios and associated equipment failures and operator actions. This process is optional, but it provides preliminary HEPs for the initial fire PRA model quantification and helps rank the fire sequences. The ranking can be used to determine which sequences might be further analyzed to reduce the calculated risk by analysis of cable separation, detailed fire modeling, or detailed human reliability evaluations.

Before quantifying an HFE, the analyst must have applied the criteria discussed in Section 4.3 for assessing the feasibility of the operator action(s) associated with that HFE. Although the feasibility assessment process begins at the identification and definition stage and is a key part of the initial qualitative analysis, new information may be available during the quantification process that would require the feasibility to be reassessed. Therefore, feasibility assessment is a continuous action step throughout the fire HRA.

The screening methodology presented next stems from NUREG/CR-6850 [1]. Based on recent plant-specific applications of the methodology, it was determined that the screening criteria for Sets 1 and 2 did not adequately distinguish between short- and long-term actions. Long-term actions are those that are not required during the early stage (e.g., the first hour) of a fire event and are not expected to be performed until approximately 1 hour after the fire-induced plant trip or until the fire is out. Therefore, short-term actions are those required within the first hour of a trip. By not distinguishing between short- and long-term actions, the NUREG/CR-6850

application of the screening criteria produced overly conservative HEPs for the longer term actions. The screening criteria for Sets 1 and 2 described next have therefore been modified to reflect the likely differences in the HEPs for long-term actions, but otherwise they are identical to the criteria presented in NUREG/CR-6850.

As discussed in NUREG/CR-6850, the screening methodology described next is a method for assigning quantitative screening values to the HFEs modeled in the fire PRA when performing Task 7, Quantitative Screening, and subsequent model refinement activities. However, because of the unique conditions created by fires, some level of analysis will be needed to determine which screening "set" (described next) is applicable.

The method supports the assignment of screening values by addressing the conditions that can influence crew performance during fires, ensuring that the time available to perform the necessary action is appropriately considered (given the other ongoing activities in the accident sequence) and that potential dependencies among HFEs modeled in a given accident sequence are addressed. Note that the criteria are best applied on a fire scenario (or groups of similar scenarios) basis, in order to decide which criteria set applies for which fire(s). For a particular HFE(s), if an appropriate set of criteria (discussed next) cannot be identified or met, no screening value should be used (i.e., a 1.0 failure probability should be assigned initially and/or a more detailed analysis be performed, depending on whether the HFE becomes important after initial model quantification).

5.1.1 Method for Assigning Screening Values to HFEs (Sets 1, 2, 3, and 4)

In the first set of criteria described next (Set 1), the goal is to determine whether the fire conditions are such that the HFEs modeled in the internal events PRA can simply be assigned the internal events PRA values modified for general fire effects during screening. Therefore, Set 1 criteria apply only to existing HFEs in the internal events PRA. If the criteria can be met, analysts still need to ensure that potential dependencies across HFEs in the models are accounted for according to the ASME/ANS Standard [2]. That is, that the fire effects and the addition of any new fire-related HFEs to the model do not significantly alter the dependencies among the internal events HFEs and their associated HEPs. Set 2 addresses a special case for HFEs modeled in related scenarios in the internal events PRA but that did not meet the Set 1 criteria. Set 3 addresses 1) new HFEs added to the fire PRA to account for fire-specific effects and 2) prior internal events PRA HFEs that had to be significantly altered or modified during the identification and definition step (see Section 3) to reflect fire effects in the fire PRA. Set 4 addresses actions involved with MCR abandonment and the abandonment decision. Each of the four sets of screening criteria and HEP screening values is presented in turn in the following subsections.

5.1.1.1 Screening Values Under Set 1

Given that the criteria for Set 1 are met, the internal events PRA probability values for the applicable HFE(s), multiplied by a factor of 10 to account for effects not covered in the internal events HEP evaluation (such as fire brigade interaction, increased workload and/or distraction issues, and other unexpected fire effects), can be used as screening values for initial evaluations of the fire PRA model in NUREG/CR-6850 [1] Task 7 and beyond.

However, if the actions can be determined to be long-term actions—that is, they would not need to occur until the fire was almost assuredly extinguished—and all Set 1 criteria are met, the

HEPs from the internal events PRA can be used. It must be clear that the fire effects would no longer be dynamic and changing, that any equipment damage will be largely assessed and understood, and that environmental effects will be stabilized and not significantly affect the ability of the operators to perform the action.

The criteria for Set 1 are derived from NUREG/CR-6850 and are as follows:

1. The fire can cause an automatic plant trip or a forced and proceduralized manual trip, and the fire does not significantly damage the safe shutdown equipment being credited for the performance of the HFE, such as the equipment being used or the related indications and instrumentation, other than discussed below. This condition demonstrates that, from the safe shutdown perspective, the context is the same and the challenge of the particular fire is not significantly different (functionally or in terms of effects on equipment) from that already considered in the internal events PRA for the applicable HFE(s).
2. No spurious behavior of instrumentation (e.g., false or lost indications) or spurious equipment actuations can occur in this fire beyond those with the following general characteristics:
   a. The spurious events are not associated with safety-related equipment and instrumentation relevant to the critical safety functions and therefore will be only minor distractions—not immediate challenges to safe shutdown.
   b. The operators can discern the events to be clearly attributable to the fire.
   c. The events do not need immediate responses or corrective actions from the crew (e.g., to prevent damage to critical safety function equipment or damage to the core) while the crew attempts to achieve safe shutdown.

   The information needed to make this determination is based on input from the cable/circuit analysis, if it is available, or the Appendix R analysis safe shutdown equipment list, if applicable.
3. One train/division of safe shutdown–related equipment and instrumentation is evaluated, based on the information available at this stage of the analysis, to be completely free of any spurious events or failures directly associated with the fire, allowing the crew to maintain the critical functions such as heat removal and RCS integrity and reach safe shutdown using the EOPs.
4. Those members of the MCR crew most directly responsible for achieving and maintaining safe shutdown (i.e., the board operators responsible for controlling and monitoring plant status and the crew supervisor responsible for reading the procedures and directing crew actions) will not have significant additional responsibilities. That is, they will be able to remain in the EOPs (as when responding to an internal event) or, if they are to follow fire procedures, those fire procedures closely resemble the EOP actions (so that the internal events PRA HFEs can still be deemed relevant for their definition and quantification). One way to demonstrate this, for instance, would be to have someone else responsible for dealing with the fire-specific response procedures and to ensure that the actions associated with those procedures do not significantly disrupt the previously mentioned MCR members' responsibilities and actions related to reaching safe shutdown. The fire-specific actions also should not divert personnel normally needed to assist the MCR crew in reaching safe shutdown.
5. There is no significant environmental impact or threat to the MCR crew (e.g., no significant smoke, potential toxic gases, or loss of lighting if not already part of the internal events PRA HFE, such as for station blackout).

6. There is no reason to suspect that the time available to diagnose and implement the action(s) being addressed would be significantly different from that in the internal events PRA-related scenario(s) for which the HFE(s) apply.
7. If any of the HFEs being modeled is a local (i.e., ex-CR) manual action originally modeled in relevant accident sequences in the internal events PRA, it should be shown that achieving the local actions will not be significantly affected by the presence of fire from an environment and accessibility perspective (e.g., no significant interference from smoke or toxic gases, either in traveling to the location of the action or in executing that action; no loss of lighting; no new high radiation threat). It should also be demonstrated that the staff assumed to conduct the action will still be available; that is, they will not be conducting other fire-related responses such as isolating electrical equipment or supporting the fire brigade. Furthermore, other conditions assumed in evaluating the corresponding internal events PRA local action (i.e., need for special tools, communication capability, and adequacy of procedures and training) should not be significantly different under fire conditions. (Note: If SCBAs are needed to carry out the local action, these Set 1 criteria are not met for that action.)

If all of the conditions for Set 1 are met, the internal events PRA HEPs for the applicable HFE(s), multiplied by a factor of 10 to account for the effects of potential fire brigade interaction and other minor increased workload and/or distraction issues, can be used as screening values for initial evaluations of the fire PRA model in NUREG/CR-6850 [1] Task 7 and beyond. In addition, if the HFEs can be determined to be long-term actions as described previously, the original HEPs from the internal events analysis can be used.

5.1.1.2 Screening Values Under Set 2

This set addresses a special case in which the Set 1 criteria related to spurious events are not met, but a reasonable screening value can still be applied. The Set 2 criteria still apply only to HFEs previously modeled in the internal events PRA. If the Set 2 criteria are met, screening values of 0.1 or 10 times the internal events PRA values, whichever is greater, can be used.[9] However, if the HFEs are long-term actions (as described previously) and meet all of the other criteria for Set 2, screening values of 0.1 or 10 times the internal events PRA values, whichever is smaller, can be used. Potential dependencies across events in a scenario still need to be examined (as discussed under Set 1), and the total joint probability of the HFEs in the scenario should be reasonable, as outlined by the ASME/ANS Standard [2].

The criteria for Set 2 are derived from NUREG/CR-6850 and are as follows:

> If all of the Set 1 conditions are met except that significant spurious electrical effects are likely to be present in one safety-related train/division (and one train/division only) of equipment and/or instrumentation important to the critical safety functions, and therefore may need some corrective responses on the part of the crew, the HFEs from similar scenarios modeled in the internal events PRA may be assigned a Set 2 screening value as long as appropriate dependencies are considered. The point of this Set 2 condition is that, in Set 1, the spurious effects are not in safety-related, critical function-related equipment and do not need any immediate response from the crew. In Set 2, the crew might have to attend

[9] The Set 2 screening adjustments are intended to conservatively bound the general fire effects on Set 1 actions modeled in the internal events PRA. Set 2 adjustments do not address operator actions added to the PRA model to address additional fire scenario concerns.

and respond to the spurious activity in the affected train/division to make sure that 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. They would still have at least one train/division of safe shutdown equipment unaffected, and they would still be likely to conduct the safe shutdown actions as indicated by the procedures without significant delays.

The information needed to make this determination is based on input from the cable/circuit analysis, if available, and should consider instrumentation beyond the set identified in the Appendix R safe shutdown equipment list (such as RWST level and AFW flow indication).

For the long-term HFEs, the fire impact to safety-related, critical function-related equipment would essentially have occurred earlier in the event, and things will have since stabilized. As with Set 1, it must be clear that the fire effects would no longer be dynamic and changing, that any equipment damage will be largely assessed and understood, and that environmental effects will be stabilized and not significantly affect the ability of the operators to perform the action.

5.1.1.3 Screening Values Under Set 3

These criteria address: 1) new HFEs added to the fire PRA or 2) prior internal events PRA HFEs that need to be significantly altered or modified in Step 1 of this procedure because of fire conditions. In such cases, existing internal events PRA HEPs either do not exist or are not appropriate as a basis for the fire PRA.

The criteria for Set 3 are derived from NUREG/CR-6850 and are as follows:

1. If the action being considered is either an MCR or local (i.e., ex-CR) manual action and is to be performed within approximately 1 hour of the fire's initiation, set the HEP to 1.0 for screening. The 1-hour limit is both a reasonable limit for early response actions that will most likely be (or need to be) completed as well as a time beyond which most plants can have additional personnel and any technical support group available at the plant site.
2. If the action is not necessary within the first hour, the fire can be assumed to be out and therefore not continuing to cause delayed spurious activity and other late-scenario complicating disturbances. Also, if there is plenty of time to diagnose and execute the action, set the HEP to 0.1 or 10 times the internal events HEP, whichever is smaller. The analyst still needs to ensure that potential dependencies across HFEs in the models and the joint probabilities of multiple HFEs are accounted for according to the ASME/ANS PRA Standard [2]. In particular, the analyst needs to verify that the fire effects and the inclusion of the new actions in the model do not create significant new dependencies among the HFEs (new and old) in the model. If unaccounted-for dependencies are likely to exist, a 1.0 screening value should be used or dependencies accounted for in some other way as part of the quantification.

5.1.1.4 Screening Values Under Set 4

This criterion addresses HFEs associated with the decision to abandon the MCR and all subsequent actions in reaching safe shutdown. Because of: 1) the unique nature of the decision to abandon the MCR, 2) the wide variability on how and where plants implement safe shutdown when the MCR is abandoned, and 3) the low likelihood that such actions could be screened, unless the applicable fire initiating frequencies are extremely low, a global screening value of 1.0

should be assigned for this entire set of actions. This acknowledges that more analysis will likely be needed for these types of scenarios and that screening is therefore not appropriate for these cases.[10]

The criterion for Set 4 is from NUREG/CR-6850:

> All HFEs involved in MCR abandonment and reaching safe shutdown from outside the MCR, including HFEs representing the decision to abandon the MCR, should be assigned screening value of 1.0.

5.1.2 Basis for Quantitative Screening Values

It is acknowledged that this set of screening values does not have a direct empirical basis. The values selected are based mainly on experience with the range of screening values traditionally used and accepted in HRA (e.g., in the HRAs performed for the NRC Individual Plant Examination Program [6]), experience in quantifying HEPs for events in NPP HRAs, experience in applying a range of HRA methods and the values associated with those methods, and experience in performing HRA in fire PRAs. The screening approach intentionally applies values that may be conservative for some cases to avoid being overly optimistic. However, this avoidance is necessary for potentially important and/or complex scenarios and associated HFEs. Table 5-1 summarizes the fire screening criteria and HEPs.

5.1.3 Single Overall Failure Probability Approach for MCR Abandonment or Alternate Shutdown

NUREG/CR-6850 [1] suggests that the use of a single overall failure probability value to represent the failure of reaching safe shutdown using alternative means can be used if the probability value is evaluated conservatively and a proper basis is provided. It notes that this approach was used in several IPEEE submittals and that, in many cases, 0.1 was used as a point-value estimate for the probability. Before crediting this approach, the analyst must have applied the criteria discussed in Section 4.3 for assessing the feasibility of the operator action(s) associated with that HFE. Additionally, Section 4.8 provides qualitative analysis considerations for modeling MCR abandonment.

This approach may be sufficient for some applications, such as cases in which MCR abandonment is not demonstrated to be risk-significant. The analyst also has the option to use the scoping approach or a detailed analysis method, as discussed in the following sections.

[10] An initial possible alternative (similar to an approach initially presented in NUREG/CR-6850 [1]) that allows the assignment of a single overall failure probability value (e.g., 0.1) to represent the failure of reaching safe shutdown using alternate means (including MCR abandonment) is described in Section 5.1.3.

Table 5-1
Screening criteria summary

Screening Criteria	Short-Term Human Actions		Long-Term Human Actions	
	Definition	**Value**	**Definition**	**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 qualitative analysis (per Section 5.1.3)			

5.2 Scoping Fire HRA Quantification

The scoping fire HRA quantification approach allows the assignment of HEPs to new HFEs identified specifically for the fire PRA (i.e., outside the internal events PRA) and to HFEs carried over from the internal events analysis that survive quantitative screening. This approach may be used in the determination and identification of risk-significant events that will require detailed analysis and could be used in lieu of the screening approach if a less conservative initial analysis is desired.

Minimum criteria must be satisfied for the scoping fire HRA approach to be used. If the criteria covered within this scoping procedure are not met, the analyst must use a more detailed HRA evaluation method. Section 5.2.1 presents these scoping entry criteria.

When the minimum criteria have been met, analysts can use the steps for assigning HEPs to new or existing HFEs detailed in the flowcharts presented in Figures 5-2 through 5-6 and discussed in associated sections. A selection scheme (see Section 5.2.5 and Figure 5-2) is provided first to direct the analyst to the correct scoping quantification guidance for the HFE being considered.

The scoping fire HRA approach is used to quantify the probability of failure of the action or actions (which may include multiple subtasks) represented within a single HFE. The flowcharts provide a way to obtain HEPs (assumed to be mean values) for four categories of actions associated with the following HFEs:

1. New and existing actions accomplished inside of the Main Control Room (MCR, Section 5.2.6 and Figure 5-3).
2. New and existing actions accomplished outside of the Main Control Room (ex-CR, Section 5.2.7 and Figure 5-4).
3. Actions associated with using alternate shutdown means as a result of either MCR habitability issues or difficulties in controlling the plant from the MCR because of the effects of the fire (Section 5.2.8 and Figure 5-5).
4. Cases in which the fire may affect critical instrumentation, creating the potential for EOCs or EOOs as a result of incorrect indications (Section 5.2.9 and Figure 5-6). The flowchart for spurious indications will support addressing spurious instrument effects for Capability Categories I and II as defined in the ASME/ANS Requirements HLR-ES-C1 and C2 [2].

Sections for each of the four categories of actions provide information on the factors expected to be important for this category of HFE and on how to use the relevant flowchart.

5.2.1 Scoping Entry Criteria

Before quantifying an HFE, the analyst must have applied the criteria discussed in Section 4.3 for assessing the feasibility of the operator action(s) associated with that HFE. Although the feasibility assessment process begins at the identification and definition stage and is a key part of the initial qualitative analysis, new information may be available during the quantification process that would require the feasibility to be reassessed. Therefore, feasibility assessment is a continuous action step throughout the fire HRA.

The *scoping* approach is a simplified HRA method that requires only a few performance shaping factors (PSFs) to be assessed. This simplified approach is appropriate only if the fire scenario being evaluated is not cognitively complex or challenging. In addition to the situations discussed next, an example of a cognitively complex or challenging scenario would be one in which the cues directly relevant to the action being modeled do not match the procedural guidance. If the cues do match the relevant procedures (as discussed in Section 5.2.3), the scoping approach would be appropriate to use—assuming that all other entry criteria are met.

There are some types of scenarios, plant characteristics, and other factors for which cognitive complexities are expected that cannot be addressed by the scoping approach. In particular, the scoping quantification approach is not considered applicable to plants that implement SISBO procedures. These procedures require the operators to travel to multiple locations and to employ complex means of communication. The complexity associated with these actions is considered beyond the scope of scoping quantification.

Another example would be analyses directed at the decision to abandon the MCR as discussed in Section 4.8. The scoping approach makes some simple assumptions about whether operators abandon the MCR and should not be used to quantify any failures associated with making this decision. The scoping approach can be used to quantify HFEs subsequent to the decision to abandon; this is discussed in detail next.

Another example of potentially cognitively complex scenarios is discussed in Section 4.10: scenarios that may include potentially distracting spurious operations (e.g., indications that are not required for safe shutdown and have not been explicitly identified as being affected by the fire because the circuit analysis has not addressed them). However, as described in Section 4.10, even the current state of the art, detailed fire HRA approaches are limited in their ability to address the impact of such potential spurious indications on operator response. The approach for these potentially complex scenarios is different because of the limitations in all HRA methods—including detailed methods. Consequently, if the analyst is reasonably confident that no information can be obtained that would allow the application of either detailed fire HRA approach, an exception can be made to use the scoping approach for associated HFEs in conjunction with the discussion in Section 4.10 to address the possible range of impacts for such potentially spurious operations through, for example, sensitivity studies.

For all other cases, the analyst should determine whether the minimum criteria given next are met. These criteria are important because they allow the scoping approach to be appropriately applied to the HFE and associated scenario by limiting the context. These minimum criteria—combined with a few elements of the selection scheme discussed in Section 5.2.5—allow the scoping approach to address only certain performance influencing factors. In addition, it should be noted that meeting these criteria establishes only the minimum criteria and does not preclude additional consideration of these PSFs later in the scoping analysis.

These minimum criteria are as follows:

- **Procedures.** There should be plant procedures (e.g., fire procedures, EOPs, ARPs, AOPs, and/or NOPs) covering each operator action being modeled. The procedures should support both the diagnosis and execution of the action, unless the execution of the action can be demonstrated as skill of the craft. *Skill-of-the-craft actions* are those that one can assume that trained staff would be able to readily perform without written procedures (e.g., simple tasks such as turning a switch or opening a manual valve as opposed to a series of sequential actions or set of actions that needs to be coordinated).

  For actions associated with the recovery of EOOs or EOCs resulting from spurious indication, explicit procedural guidance (see Section 5.2.9 for guidance on dealing with these HFEs) may not be available. In these cases, operators may be able to rely on the scenario context and additional cues (in conjunction with the existing procedures) to recover those errors. An argument can be made that the existing procedures, in conjunction with operator training and available cues, will be adequate to support the recovery of the errors. If analysts rely on such arguments, they should be well documented and confirmed by appropriate plant staff (e.g., operators and trainers).

- **Training.** Operators should have received training on the procedures being used and the actions being performed. The training should establish familiarity with the procedures, the equipment needed to perform the desired actions, and the steps required to successfully execute the action. The training should be performed according to the plant's normal training practices and, if appropriate, include special considerations given that the desired actions will need to be carried out during a fire (e.g., wearing SCBA while performing the action). When subtasks must be coordinated among more than one person to complete the action, the training should also cover the way in which the coordination and communication aspects of the action should be conducted.

- **Availability and accessibility of equipment.** All equipment and tools needed to perform the modeled human actions during a fire should be readily available and accessible. The time needed to access this equipment during fire scenarios will be included in estimating response execution times (discussed further next).

These criteria are important because they allow the scoping approach to be appropriately applied to the HFE and associated scenario by limiting the context. These minimum criteria, combined with a few elements of the selection scheme discussed in Section 5.2.5, allow the scoping approach to address only certain performance influencing factors.

5.2.2 Calculation of Time Margin

One of the key inputs to the scoping approach is time margin. *Time margin* is the difference between the total available time and the time required—essentially the extra time available—and is used to represent a continued emphasis on sufficient time for operator action and other factors not addressed in the feasibility assessment. For example, a feasibility assessment does not ensure that the action would repeatedly be performed successfully (i.e., the feasibility assessment does not address the reliability of the action). As discussed in Section 4.3, in spite of plant staff's best efforts, there may be conditions that are difficult, if not impossible, to account for. Furthermore, the fire situation may introduce additional variability in plant and operator responses that were not fully incorporated in the feasibility assessment. These variabilities and uncertainties could affect the reliability of the performance of the action. Therefore, to more thoroughly ensure the reliability of the action, the time available should be greater than the time required to account for these uncertainties and variabilities in time estimates.

A tradeoff exists between the extent to which the feasibility assessment is realistic and the uncertainties to be addressed as part of justifying that there is adequate time to perform the action. For instance, more realistic demonstrations of feasibility (e.g., systematic walk-throughs while simulating fire conditions) translate to less uncertainty with regard to justifying that there is adequate time. Similarly, gathering information from a larger number of simulations with additional crews can increase the confidence in the assessed crew response times.

One technique used to address the potential shortcomings in plants' ability to realistically simulate plant conditions during fires and the potential variability in crew response times is to require particular time margins (i.e., the difference between the total available time and the time required, essentially the extra time available) to obtain certain HEPs. Therefore, a key factor in applying the scoping quantification approach is the time margin available for a particular action.

Figure 5-1 presents a timeline illustrating the components involved in calculating time margin.

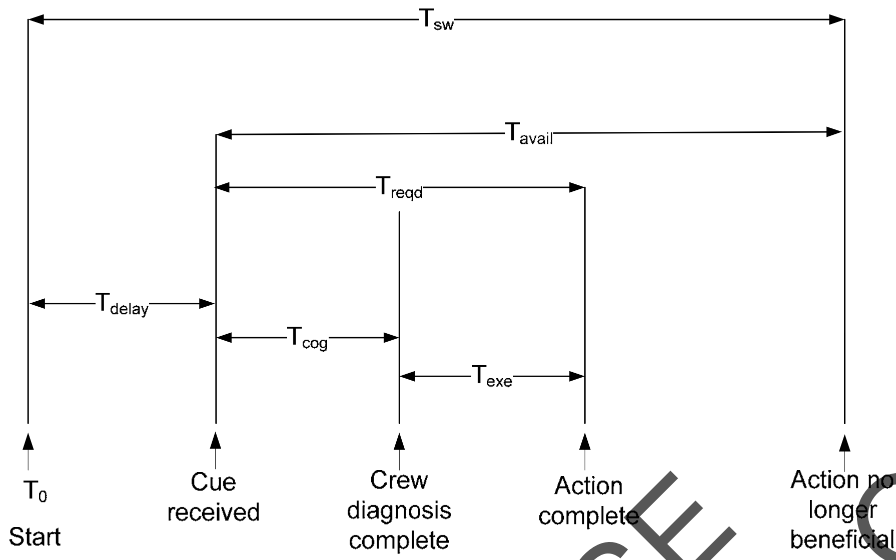

Figure 5-1
Timeline illustrating total time available, time required, and the resulting time margin

Section 4.6.2 defines each of the terms in the timeline. In this diagram, TSW is the total time available from the initiating event (e.g., reactor trip) until the action is no longer beneficial. The action time window, Tavail, is the amount of time available to perform the action, including the cognition and execution portions of the HFE. The other variables are as follows: T0 is the start time (typically the initiating event), Tdelay is the time from the initiating event until the cue(s) for the action is received, Tcog is the time to diagnose the problem and formulate the response, and Texe is the execution time—including transit, donning of PPE, and manipulation of components.

For quantification of the HFEs using the scoping analysis, the timing terms are used to calculate the time margin. Time margin is defined as the ratio of time available for the recovery action to the time required to perform the action (Tcog+Texe) and is calculated as follows:

$$\text{Time Margin (TM)} = \frac{T_{avail} - T_{reqd}}{T_{reqd}} \times 100\% \qquad \textbf{Equation 5-1}$$

$$\text{Time Margin (TM)} = \frac{\left[\left((T)_{sw} - T_{delay}\right) - \left(T_{cog} + T_{exe}\right)\right]}{\left(T_{cog} + T_{exe}\right)} \times 100\% \qquad \textbf{Equation 5-2}$$

Time margin is explicitly considered in the scoping quantification to account for potential shortcomings in the plants' ability to simulate plant conditions during fires and the potential variability in crew response times. In addition, different time margins may be required if the presence of certain conditions (e.g., short versus long timeframe events or simple versus complex actions) suggests the potential for greater sensitivities to the effects of the fire or greater variability in crew response times.

Time margins should be calculated for all actions or sets of actions (underlying a given HFE) being modeled and quantified using the scoping approach; in at least some cases, the explicit development of a timeline or a timeline analysis can be useful. Recall that some actions underlying an HFE may require multiple subtasks to be performed in parallel or may involve a

mix of both serial and parallel actions. In addition, some tasks may overlap. In these cases, the determination of the time margin may not always be as straightforward as illustrated previously. The time for the tasks taken together, including where they overlap, needs to be considered in determining the available time margin. For example, an action may involve several subtasks that, if performed serially, would take 30 minutes to complete. However, if two people are involved and two of the subtasks can be performed in parallel, the execution time may require only 20 minutes (or at least less than 30 minutes). In this case, less extra time would be needed to obtain a 100% time margin. Although the application is somewhat different, Appendix A of NUREG-1852 [7] provides guidelines and examples for using timelines to demonstrate sufficient time to perform a range of combinations of serial and parallel subtasks.

When timing data are collected for crew response times, HRA analysts need to collect a range of times in addition to the point estimate of an average crew; this is especially important when the required time is close to the time available. As noted in Sections 4.3.4.1 and 4.6.2, potential uncertainty in the timing data is important for cases in which a small change in the estimation of the time required could change the operator action from feasible to infeasible or significantly change the reliability of the action. The scoping quantification approach can include certain "tipping points" where a few additional minutes of time in the estimate can push the action into a different time margin regime. In these cases, it is recommended that the analyst choose to initially use the more conservative timing data (and resulting HEP) and refine the data later if the HFE significantly impacts the fire PRA model quantification results. Alternatively, the analyst could run several test cases to evaluate the impact of timing variability and perhaps quantify the HFE with separate timing cases if the impact is strong enough to warrant it. HEP adjustments for uncertainties in response times caused by crew variability and other factors are accounted for later in the scoping process based on the available time margin.

5.2.3 Assess Key Conditions and PSFs

In applying the scoping flowcharts, in addition to addressing the timing issues discussed previously, decisions must be made regarding particular conditions and PSFs that could affect the performance of the actions. Some of the decisions are required in all of the flowcharts; others are specific to particular flowcharts. General guidance for making these decisions is provided in this section; however, in some cases, details associated with particular conditions and PSFs are specific to particular flowcharts. These details are discussed in the sections providing guidance for the specific flowcharts.

It should be noted that some of the decisions that need to be made will not be made exclusively by the HRA analysts. For example, explicit criteria were developed in NUREG/CR-6850 [1] for determining when smoke, toxic gases, and heat levels would be high enough to require MCR abandonment as a result of habitability issues. Similarly, questions are asked in all of the flowcharts regarding smoke levels for areas in which operators will be performing actions or through which they will have to pass on the way to perform actions. This information is used to determine whether SCBAs will be needed or whether there may be smoke dense enough to cause visibility problems and prevent the action from being taken. These determinations will be part of the fire modeling tasks (NUREG/CR-6850 Task 8, Scoping Fire Modeling, and Task 11, Detailed Fire Modeling), and the information will have to be supplied to the HRA analysts based on what are likely to be conservative estimates of the likely smoke, toxic gases, and heat levels in those areas and whether they could be high enough to require SCBAs or severely affect

visibility. HRA analysts should participate in this process to help ensure that relatively conservative estimates of the fire effects are made.

The following conditions and PSFs are important to the scoping flowcharts and are addressed accordingly:

- **Do the procedures match the scenario?** An important question asked in several of the flowcharts concerns the diagnosis of a given action. In particular, the question asks whether the cues being received (that are directly relevant to the action being modeled) match the procedural guidance. In other words, is it expected that the cues and their timing will be correct and consistent with the procedures? Another way to ask the question is whether the procedures should be relatively easy to follow given the pattern of indications. If the cues and their timing are expected to be correct given the accident conditions and are consistent with the procedures, the diagnosis for the need for the action can be considered relatively simple and straightforward. However, if the cues for an action are not expected to match the procedures closely, it should be assumed that the diagnosis will be difficult, and the HEP for the action should be set to 1.0 (or a detailed analysis performed). This question is not asked in the scoping flowcharts when it is known that one or more key indicator(s) specific to an action will likely be affected by fire (i.e., in cases in which the fire could have effects on specific instrumentation and EOOs or EOCs are possible [see the SPI flowchart in Figure 5-6]). In these cases, the procedures (related to determining the needed action) are not likely to match the pattern of cues.
- **Response execution complexity.** The complexity of the actions involved in executing the response after the diagnosis is made is addressed in all of the specific scoping flowcharts. Execution complexity is quantified only at two levels—either high or low. In deciding on the level of execution complexity, several aspects are evaluated (note that the following guidelines apply to both MCR and local actions):
  - **Single-step actions.** If an action requiring only a single step (e.g., simply starting a pump as opposed to aligning for feed and bleed) can be performed by a single crew member and the action is supported by clear procedures (i.e., trained personnel should be able to follow them straightforwardly) or can be considered skill-of-the-craft, low complexity can generally be assumed.
  - **Multiple step actions.** If the HFE requires multiple steps to be completed successfully, complexity may increase. If the execution of the multiple steps can be performed by single crew members working independently of what other personnel (if any) involved in the action are doing and the execution of the steps is supported by either clear procedures (trained personnel should be able to follow them straightforwardly) or the actions can be considered skill-of-the-craft, low complexity can generally be assumed. However, if there are concerns that procedures needed to support the actions may be ambiguous, that any of the steps may be difficult to complete correctly, or that difficult judgments may be required (even if only for some personnel), high complexity should be assumed.
  - **Multiple crew members performing coordinated steps.** If multiple crew members are required to complete an action and the steps require coordination and communication among team members to successfully complete the action, high complexity should be assumed. This will be true when the steps must be performed in a particular sequence and when the steps involve a combination of sequential and parallel steps. Generally, high complexity should be assumed for any actions requiring coordination and communication

among crew members. Exceptions would be well-trained, EOP-based actions in the MCR that are part of the expected response to an initiating event—but even these actions should be examined carefully for potential ambiguity and difficulty.

– **Multiple location steps.** During the execution of an action, multiple locations may need to be visited either by different members of the staff or by one staff member. The necessity of visiting multiple locations (e.g., different electrical cabinets or different rooms, not just different panels in the MCR) increases the complexity, particularly if coordination and communication among staff members is required. Generally, if multiple locations must be visited to complete the action, high complexity should be assumed.

– **Multiple functions.** Multiple functions may need to be addressed in the execution of an action (e.g., both electrical alignment and mechanical) that will increase the execution complexity of the action. When multiple functions must be addressed, the complexity should generally be assumed to be high.

– **Accessibility of location or tools.** Factors such as excessive heat, the absence of adequate lighting, or the presence of the fire brigade in the area may make it more difficult for the operator to reach the location of the actions or to access the tools necessary to perform the action. To the extent that the action would become more difficult to complete because of such conditions, high complexity should be assumed.

As discussed in Section 4, Qualitative Analysis, other factors can contribute to complexity. For example, time pressure or stress can make even simple actions seem more difficult. Therefore, although this guidance can be used in most cases to determine whether complexity is high or low, if additional information is known about the conditions under which an action will be performed (based on a qualitative analysis) and those conditions may add to the complexity, they should be considered in an assessment of complexity level—generally leading to low complexity actions being assessed as high complexity.

It should be noted that several factors that could add to complexity are already included in the scoping flowcharts. In addition, the assessment of feasibility (as described in Section 4.3) will show that the action is not so complex that it cannot be performed in the time available; the time margin is intended to account for other factors that may not have been explicitly included in the feasibility assessment or covered in the scoping flowcharts.

- **Timing of cues for the action relative to expected fire suppression time.** An assumption of the scoping flowcharts is that actions that have to be performed during an ongoing fire (whether the action is inside or outside the MCR) will be more susceptible to both the direct and indirect effects of the fire. Therefore, two of the flowcharts (regarding MCR actions and ex-CR actions; Figures 5-3 and 5-4) explicitly ask whether the cue(s) for an action will occur while the fire is ongoing. Based on the information in the original NUREG/CR-6850 [1] which was further developed as FAQ-08-0050 [8] and then published as NUREG/CR-6850 Supplement 1 [1], for the application of the scoping flowcharts it is assumed that most fires (with exceptions noted next) will be extinguished or contained within 70 minutes of the start of the fire. As such, upon initiating the actions listed in Figures 5-3 and 5-4, the time from the beginning of the fire to the presentation of the cue for an action needs to be determined. For the scoping analysis, the start of the fire is considered concurrent with the initiating event (e.g., reactor trip). Although this is rarely the case in actuality, estimating the times this way allows a conservative estimate of the effect of the fire on the diagnosis and execution of the action.

Depending on when the cue(s) occurs, analysts will take different paths through the flowcharts. If the type of fire is known, the analyst may use the timing estimates for fire suppression supplied in FAQ-08-0050 to determine whether the fire is ongoing. Table 5-2 reproduces the table presented in FAQ-08-0050 outlining expected suppression rates. For each suppression time, the table provides the fraction of fires of a given type that would still be ongoing at that time. The analyst should use at least the 99th percentile value (i.e., numerical results equal 0.01 and below) as a cutoff for the given fire type. If the type of fire is not known, the analyst may use the "All Fires" category. For this category, the 99th percentile fire suppression value corresponds to a time of 70 minutes; that is, the analyst should assume that the fire has not been suppressed or contained if the cue for a given action is expected to be received within the first 70 minutes after the fire has started or the plant has tripped. Furthermore, for the modeling of actions during more challenging fires (i.e., turbine-generator [T/G] fires, outdoor transformers, high-energy arcing faults, and flammable gas fires), the analyst should always assume that the cue occurs before the fire has been suppressed, regardless of when the cue occurs relative to the start of the fire. HFEs quantified in these situations will be assigned a slightly higher HEP to account for direct and indirect effects of an ongoing fire.

- **Time available.** The *time available* for an action is defined as the amount of time from the occurrence of the cues for action until the action is no longer beneficial.[11] For actions that have a short amount of time available, additional consideration is given to the time margin and to determining feasibility. For the scoping flowcharts, it is assumed that having a short amount of time available (≤30 minutes, approximately) will be more susceptible to diversions and distractions caused by the occurrence of the fire in the plant. Therefore, for HFEs in which there is a short T_{avail}, these are given different treatment in the scoping flow charts than longer T_{avail} (>30 minutes, approximately). This different treatment is applied whether the cue for the action occurs during ongoing fire suppression efforts or afterward. If the time available for action is ≤30 minutes, the analyst is directed one way in the flowchart and in another direction if the available time is >30 minutes.

[11] From Figure 5-1, the *time available* for action is defined as T_{avail}.

Table 5-2
Numerical results for suppression curves

Time (minutes)	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

*A value of 1E-3 should be used.

Note: Values provided in this table are non-suppression probabilities as a function of time for each fire type [1].

- **Levels of smoke and other hazardous elements in action areas.** All of the specific scoping flowcharts address the levels of smoke and other hazardous elements (referred to as *smoke levels*) present in areas of the actions or in areas through which personnel must travel to reach those areas. This information is used to make yes/no decisions with respect to whether SCBAs will be needed or whether there may be smoke dense enough to cause visibility problems and prevent the action from being accomplished. As briefly discussed previously, these determinations will be part of the fire modeling tasks (NUREG/CR-6850 [1] Task 8, Scoping Fire Modeling, and Task 11, Detailed Fire Modeling), and the information will have to be supplied to the HRA analysts based on what are likely to be conservative estimates of the likely smoke levels in those areas and whether they could be high enough to require SCBAs or severely affect visibility. Plant criteria for donning SCBAs may also be taken into account. Note that smoke removal systems that can be assumed to be functioning can be taken into account in estimating smoke levels. If analysts are not sure about the potential effects of likely smoke conditions on the ability of crews to respond, conservative assessments can be made. For example, if some smoke effects are likely, given the location of the fire, but it is not known whether SCBAs will be needed, it would be conservative to assume that they would be needed.

  Branches for quantification in the scoping flowcharts are based on the following levels of smoke within the action areas:

  - No smoke or hazardous elements are present.
  - Smoke or hazardous elements are present but at a level low enough that the use of SCBA is not required.
  - Smoke or hazardous elements are at a level high enough that SCBA is required.
  - Smoke levels are high enough to affect visibility and prevent the execution of the action. (Note that actions directly in the vicinity of the fire cannot be credited).

  The guidelines for addressing smoke effects that could lead to MCR abandonment as a result of habitability issues are addressed separately in Section 5.2.5.1 (which describes the scheme for selecting the appropriate flowcharts for the action) and in the section describing the alternate shutdown flowchart (Section 5.2.8).

- **Accessibility.** In the scoping flowcharts for ex-CR actions (see Figure 5-4) and MCR abandonment actions (see Figure 5-5), analysts need to determine whether the action location will be accessible when the fire is still assumed to be ongoing. This question is concerned with certain areas being blocked or otherwise inaccessible because of the presence of the fire and ongoing attempts to suppress it. Analysts must determine whether the action needs to be performed in the vicinity of the fire or if the presence of the fire and actions associated with suppressing it could prevent operators from being able to reach the action location. If either of these is true, the action cannot be credited.

5.2.4 Basis for Scoping HEPs

The scoping quantification guidance offered here is intended to be a simplified and conservative HRA approach. The guidance is *simplified* in the sense that recommended HEP values are associated with a minimal number of influencing factors (e.g., performance shaping factors or

plant conditions), resulting in less effort being required of the HRA analyst. Similarly, the guidance is *conservative* in the sense that recommended HEPs are expected to be higher in value than those that could be derived if a more detailed and time-consuming HRA was performed.

As with the screening HEPs assigned in Section 5.1, it is acknowledged that the HEP values used in the scoping analysis do not have a direct empirical basis. The values selected are based mainly on experience with the range of values traditionally used and accepted in HRA (e.g., in the HRAs performed for the NRC Individual Plant Examination Program [9] and the NRC Individual Plant Examination of External Events Program [6]), experience in quantifying HEPs for events in NPP HRAs, experience in applying a range of HRA methods and the values associated with those methods, and experience in performing HRA in fire PRAs. The values were selected with the goal of being somewhat conservative while crediting reasonable time margins and other PSFs. A discussion of the basis of the HEPs quantified through the use of the scoping fire HRA method is presented in Appendix F.

5.2.5 Guidance for Using the Selection Scheme

In Section 3, Identification and Definition, HFEs are identified and categorized as follows:

- Internal events operator actions (existing operator actions from the internal events PRA model)
- Fire response operator actions (operator actions explicitly called out in the fire procedures)
- Undesired operator actions (as a result of spurious instrumentation)

Although this classification aids in understanding how the HFE was identified, for the purposes of scoping fire HRA quantification, the HFE needs to be further classified.

In the scoping fire HRA quantification approach, HFEs are treated based on conditions within the MCR, the location of the diagnosis and execution of the actions associated with the HFE (MCR or ex-CR), and the condition of relevant instrumentation. The selection scheme (see Figure 5-2) uses pertinent questions to determine which action is being quantified and to direct the analyst to one of the following flowcharts: MCR action, ex-CR or local action, alternate shutdown, or recovery of error resulting from spurious instrumentation.

In some instances, the HFE may be quantified within the selection scheme. For instance, the first question in the selection scheme flowchart (Figure 5-2, Decision 1 [D1]) asks whether the minimum criteria have been met (as discussed in Section 5.2.1). If the criteria have not been met, an HEP of 1.0 can be assigned immediately and detailed analysis can be performed (if desired).

Two other cases exist in the selection scheme for which the action is assumed to fail and an HEP of 1.0 may be assigned. First, prior to entering the "decision diamond," determining whether the action is performed in the MCR or locally (D5), the question of whether the procedures match the scenario is asked (D4)—that is, do the cues received by the control room staff to support diagnosis match the procedural guidance? (See Section 5.2.3 for guidance on this decision.) If the cues do not match the procedures, it is assumed that diagnosis may be difficult and the action is assumed to fail (i.e., HEP = 1.0). In the second case, for the execution of ex-CR actions, it is assumed that procedures are present for directing the steps of the action or that the execution is skill-of-the-craft (D6). Again, if these procedures or skills do not exist, the action is assumed to fail (HEP = 1.0) from the scoping perspective.

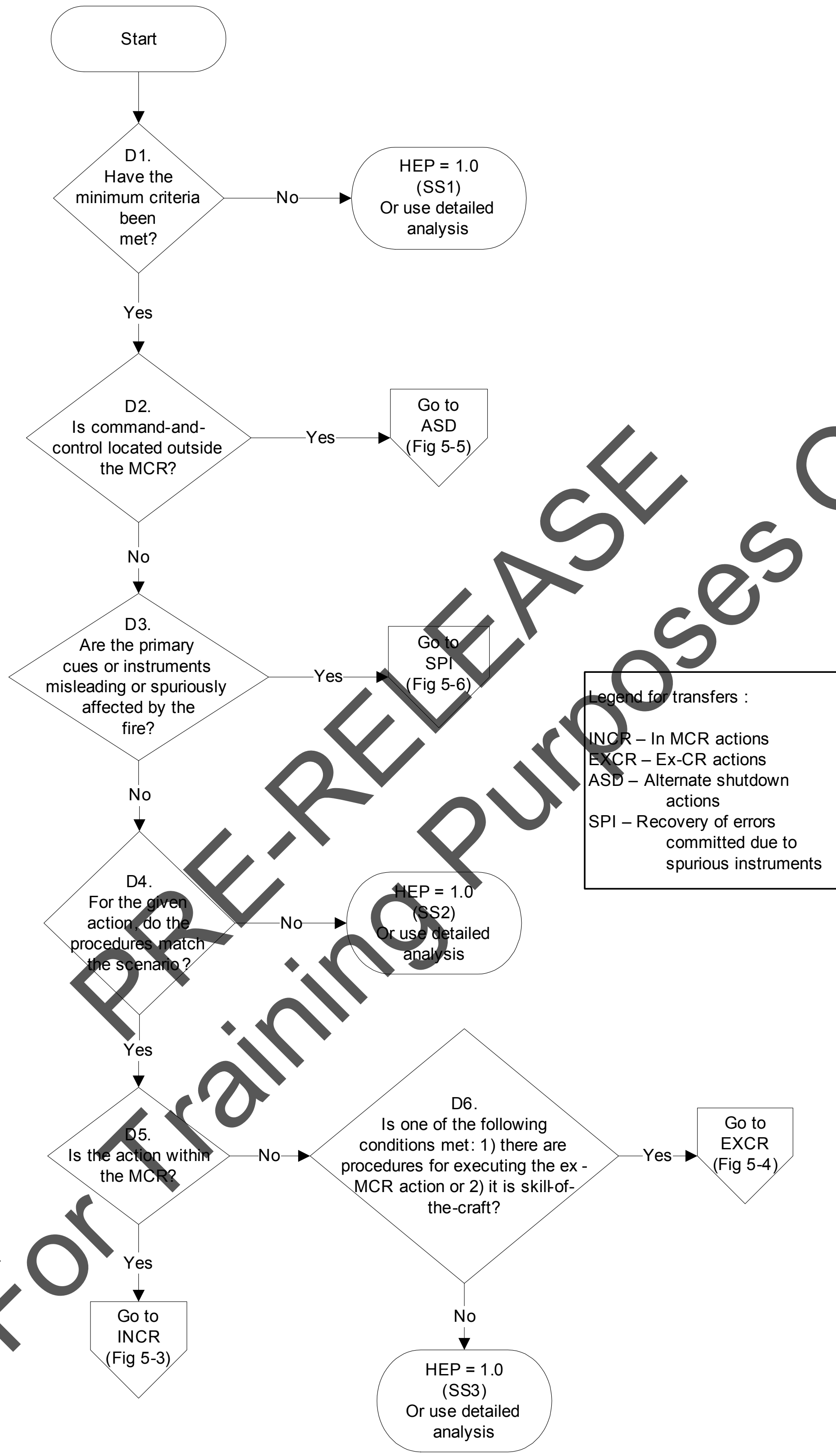

Figure 5-2
Scoping HRA selection scheme

Notice that the HEPs assigned in the selection scheme flowchart are identified with labels (e.g., *SS1*). These labels—provided for all HEPs assigned through the use of the flowcharts—are provided primarily to help later in tracing the way in which a particular HEP was decided on in the analysis. The specific acronym associated with each HEP is determined based on the flowchart used. Specifically, the labels represent which flowchart was used in assigning the HEP as follows:

- SS = selection scheme
- INCR = in MCR
- EXCR = ex-CR (actions normally performed locally)
- ASD = alternate shutdown (including MCR abandonment because of habitability or transferring command and control to outside the MCR because of an inability to control the plant)
- SPI = spurious instrumentation

Although some HFEs may be quantified with the use of the selection scheme alone, most HFEs will be directed to the other flowcharts for quantification. A series of questions is asked in the selection scheme to determine which of the flowcharts is appropriate for quantification. After determining that the minimum criteria have been met (D1), the next decision (D2) determines whether the analyst will be directed to the flowchart quantifying alternate shutdown, including MCR abandonment (Figure 5-5; ASD) based on the need to relocate command and control (i.e., the location of diagnosis, communications, and coordination of the action) outside the MCR.

Discussion and guidance on interpreting the questions asked in the selection scheme (Figure 5-2) and the transitions to other flowcharts are presented in the following subsections. Following these discussions, separate sections provide guidance on using the other flowcharts and the resulting scoping fire HFE quantification:

- Section 5.2.6: HFEs composed of actions diagnosed and executed within the MCR (INCR)
- Section 5.2.7: HFEs composed of actions diagnosed in the MCR but executed locally (EXCR). This includes remote shutdown actions where command and control is still being performed in the MCR but, because of the effects or potential effects of the fire, some actions must be performed outside the MCR.
- Section 5.2.8: HFEs associated with actions related to alternate shutdown, including abandoning the MCR because of habitability or problems with monitoring or controlling the plant from the MCR, resulting in relocating command and control outside the MCR (ASD)
- Section 5.2.9: HFEs resulting from responses to spurious indications (SPI)

5.2.5.1 Alternate Shutdown (D2)

For fires that require that command and control be located in an area other than the MCR at any time during the scenario, either because of an uninhabitable environment in the MCR or because plant monitoring **and** control cannot be achieved within the MCR (i.e., an inability to control key safe shutdown equipment), the crew will need to leave the MCR and achieve safe shutdown from ex-CR locations. This decision to use alternate shutdown means that the execution and the diagnosis of subsequent actions occur outside the MCR. The decision to abandon the MCR

should not be quantified using the scoping approach; however, all actions following the decision may be quantified using the scoping approach. Section 11.5.2 of NUREG/CR-6850 [1] provides criteria for determining when the MCR would need to be abandoned because of habitability issues. To establish the timing of this event, it is suggested that at least one of the following criteria from NUREG/CR-6850 be satisfied:

- The heat flux at 6 ft (1.8 m) above the floor exceeds 1 kW/m^2 (relative short exposure). This can be considered the minimum heat flux for pain to skin. Approximating radiation from the smoke layer as $q_r'' = \sigma * T_{sl}^4$, a smoke layer of around 95°C (200°F) could generate such heat flux.
- The smoke layer descends below 6 ft (1.8 m) from the floor, and the optical density of the smoke is less than 3 m^{-1}. With such optical density, a light-reflecting object would not be seen if it is more than 0.4 m away. A light-emitting object will not be seen if it is more than 1 m away.
- A fire inside the main control board, damaging internal targets 7 ft (2.13 m) apart.

If any of the criteria is met, subsequent actions will need to be quantified as alternate shutdown actions, and analysts will follow the selection scheme flowchart to the alternate shutdown (ASD) flowchart for each action (see Figure 5-5).

When habitability is not an issue, it is reasonable to expect that the MCR would not be completely abandoned.[12] Therefore, the HRA should focus on how the crew would need to respond to the scenario given the specific fire effects. In particular, for a given fire and its expected effects on equipment, analysts will need to determine whether the crews would need to switch command and control to an ex-CR location (alternate shutdown) or whether it would be possible to direct the actions and control the plant from the MCR. This determination should be based on interviews with plant operators and trainers and an examination of the plant fire procedures. However, the decision to abandon should not be quantified using the scoping approach.

If the effects of the fire could be significant enough that relocating command and control to outside the MCR (e.g., switching to an ASP or an ASD strategy) would probably be required (e.g., a large fire in the cable spreading room), analysts will need to estimate the time at which switchover is likely to occur relative to the start of the initiating event.[13] At that point, the analyst can quantify the switchover actions using the ex-control room flowchart (EXCR), but all subsequent actions would be quantified using the ASD flowchart. The timing for the subsequent actions will have to take into account the time to perform the switchover and the timing of the critical cues at the alternative locations. If it is determined that the operating crew could reach safe shutdown using ex-CR actions, as necessary—without relocating command and control—the HFE for these actions would be quantified using the EXCR flowchart.

[12] Analysts may want to determine whether there are exceptions to this expectation or if there are plant-specific reasons that such an assumption would not be valid.

[13] Estimating the need for switchover and when it may occur may require nontrivial analysis of the plant state. If the information cannot be obtained, either the screening value presented in Section 5.1.3 or detailed analysis may be used.

A scenario involving alternate shutdown (switching command and control to outside the MCR) introduces a level of complexity that cannot be adequately addressed by quantifying these actions as usual local (i.e., ex-CR) actions. In general, the inability to use the EXCR flowchart results from the need to relocate command and control to an area outside the MCR so that diagnosis and coordination of the actions are done at some remote location(s). Furthermore, by operating at a remote location, it is likely that many factors may introduce more serious challenges to operator success under these conditions, for example:

- Less available instrumentation and controls
- The need for the organized involvement of many operators in various locations in the plant
- The need for communications among personnel at distributed locations
- Less familiar procedures
- Less frequent training
- More time needed to reach the necessary locations
- More time needed to perform actions that in other situations could easily be done in the MCR

In general, if it is known that habitability or monitoring and control of the plant from the MCR would not be affected to the extent that switching plant command and control outside the MCR would be required, analysts will progress in the selection scheme to the next question about indicators for the specific actions being affected by the fire (D3).

5.2.5.2 Actions Caused by Spurious Instruments (D3)

According to the fire PRA Standard [2], analysts will need to determine whether there are particular actions (either EOCs or EOOs) that could be caused by the effects of single spurious instruments or by combinations of spurious instruments if the contribution to risk would be high (see ASME/ANS Requirements HLR-ES-C1 and C2 for more detail [2]). Therefore, the next decision diamond (D3) asks whether the primary cues or instruments are damaged or spuriously affected by the fire, causing them to be misleading. A *cue* is a signal or alert (plant parameter, procedure step, or plant condition) that prompts an operating crew to take a specific action. An operator action could have multiple cues; the first cue received and responded to is considered the *primary cue*. A *secondary cue* is one that occurs after the primary cue or that occurs in conjunction with the primary cue but is acknowledged only for verification of the primary cue. See Section 4.3 for further discussion of primary cues.

Therefore, if cues or MCR instruments are misleading or spuriously affected by the fire such that the operator has difficulty in diagnosis or could be led to either an EOC or EOO, the SPI tree must be used. Instruments spuriously affected by the fire that have no direct bearing on the action at hand do not require the analyst to use the SPI tree.

If the cues or instruments are fed by "protected" cables, they can generally be assumed to be unaffected by the fire. Some instruments and cues associated with safety systems—in particular, those associated with achieving and maintaining safe shutdown conditions—are considered *protected* in accordance with 10 CFR Part 50 Appendix R [10] or as *unaffected* in an NFPA 805 [11] project.

For scoping quantification, an instrument is considered *protected* if it is free of fire damage; such as cables are not routed through the fire area in question or if the cables are protected with an electrical raceway fire barrier system (ERFBS) sufficient for the postulated HFE and the given fire scenario.

5.2.5.3 Diagnosis Complexity (D4)

If the action being quantified deals neither with alternate shutdown nor with the response to spurious instruments caused by the fire, the final two choices for quantification are based on the location of the execution of the action.

The PRA models will include both existing HFEs from the internal events models and new HFEs based on the presence of the fire, the initiating event, and the plant-specific fire procedures. These HFEs will represent both MCR and ex-CR actions, with the diagnosis for the action taking place in the MCR. They will include the traditional human actions modeled in PRA but may also include fire response actions such as the fire manual actions implemented in procedures to meet deterministic requirements (e.g., see NUREG-1852 [7]). For HFEs that involve multiple actions that occur in both the MCR and ex-CR, the EXCR flowchart should be used (because all of the HEPs for the EXCR flowchart are higher than those for the INCR flowchart, and the scoping approach has been limited to contexts for which diagnosis is not complex; therefore, diagnosis will not be considered a dominant influence).

As discussed previously, a preliminary question (Figure 5-2, D4) in the quantification of these MCR and ex-CR actions asks whether the procedures match the scenario (see Section 5.2.3 for guidance). The intent of this question is to assess the difficulty in diagnosing the problem. If the specific cues for the action do not match the procedures, it is assumed that diagnosis will be difficult and that the event needs to be evaluated using a different method.

5.2.5.4 MCR and Ex-CR Actions (D5 and D6)

If the execution of the action occurs within the MCR, the analyst is directed (D5) to Figure 5-3, the INCR flowchart. Otherwise, quantification is based on the action being executed locally (i.e., outside the MCR).

Prior to transferring to the flowchart for quantifying ex-CR actions (Figure 5-4, EXCR), the final question asks whether either of the following conditions exists (D6):

1. Procedures are available to support executing the action outside the MCR.
2. The action (and related subtasks) can be assumed to be skill-of-the-craft, therefore does not require procedures.

Skill-of-the-craft actions are those that one can assume trained staff would be able to readily perform without written procedures (e.g., simple tasks such as turning a switch or opening a manual valve as opposed to a series of sequential actions or set of actions that need to be coordinated). If neither of these conditions is true, the action is assumed to fail (HEP = 1.0). If one of the conditions applies, the analyst is directed to Figure 5-4 to quantify the ex-CR action.

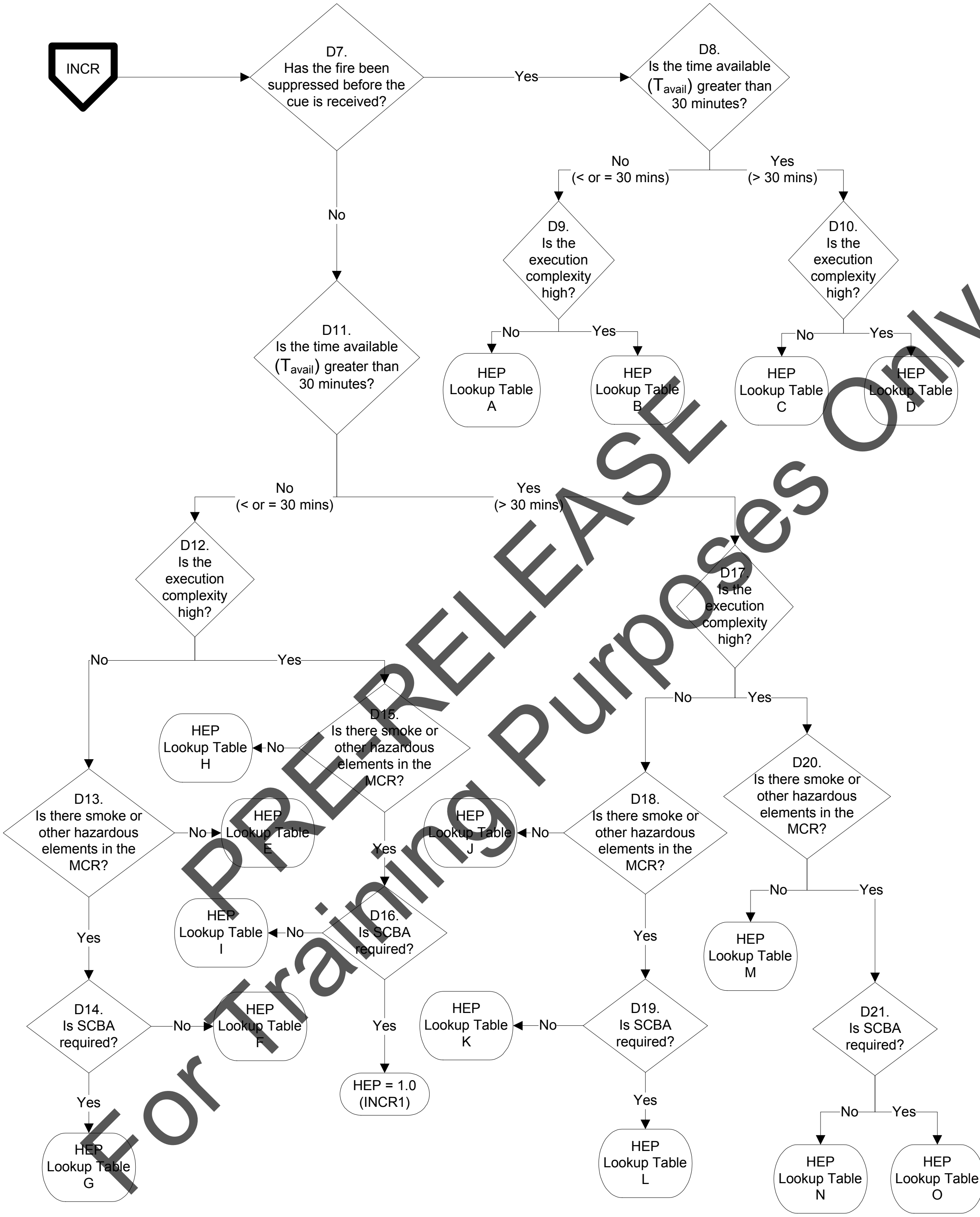

Figure 5-3
INCR: Scoping HRA for in-MCR actions

Figure 5-4
EXCR: Scoping HRA for ex-CR actions

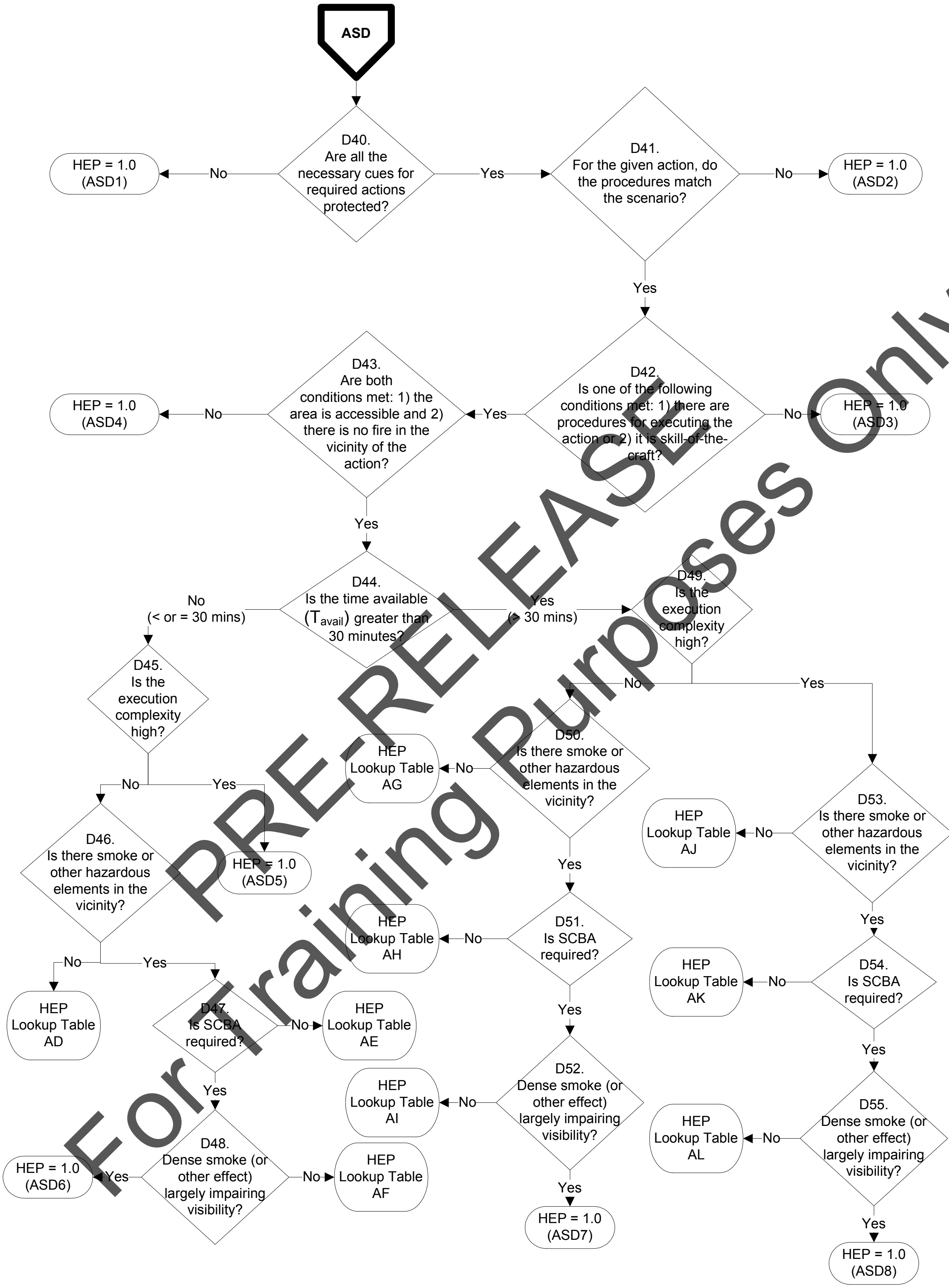

Figure 5-5
ASD: Scoping HRA for alternate shutdown actions

Figure 5-6
SPI: Scoping HRA for EOC or EOO resulting from spurious instrumentation

5.2.6 Guidance for Using the INCR Flowchart for In-MCR Actions

The flowchart presented in Figure 5-3 (INCR) walks through the steps of assigning scoping HEPs to HFEs within the MCR. This flowchart is intended to be used for new HFEs identified outside the internal events PRA or existing HFEs from the internal events analysis.

The flowchart is used for actions in which the diagnosis and execution of the action take place within the MCR. Following the guidance provided in Section 5.2.1, analysts will generally need the following information to apply the flowchart:

- The general expectations for the time at which the cue for an action would occur relative to the start of the fire (e.g., based on guidance in FAQ-08-0050 [1, 8], does the cue occur within 70 minutes of the start of the fire, or does it occur after that 70-minute time frame). If the cue for an action occurs before the fire has been suppressed, different paths are taken through the flowchart (D7). Note that for more challenging fires—such as fires of turbine generators, outdoor transformers, high-energy arcing faults, and flammable gas fires—the analyst should always assume that the cue occurs before the fire has been suppressed, regardless of when the cue occurs relative to the start of the fire.
- A determination of the action time window[14] from the time at which the cue for the action occurs until the response is no longer beneficial. If the time window for an action is approximately ≤30 minutes as opposed to >30 minutes, different paths are taken through the flowchart (D8 and D11).
- The level of execution complexity expected; high or low indicates different paths (D9, D10, D12, and D17).
- The expected level of smoke and other hazardous element effects in the MCR (D13, D15, D18, and D20). The presence of smoke leads to a different path. Note that smoke removal systems that can be assumed to be functioning can be taken into account in estimating smoke levels in the MCR.
- A determination of whether SCBAs will be needed (D14, D16, D19, and D21).
- An estimate of the time margin for use in the lookup tables.

If analysts are not sure about the potential effects of likely smoke conditions on the ability of crews to respond, conservative assessments can be made. For example, if some smoke effects are likely given the location of the fire but it is not known whether SCBAs will be needed, it would be conservative to assume that they would be needed.

Based on the answers to each question in the flowchart, the action is either assumed to fail (i.e., HEP = 1.0) or the analyst will be directed to find the HEP value in the lookup tables. The lookup tables for the INCR flowchart are located in Table 5-3. Within the lookup table, the HEP assigned for each action is based on the time margin available.

[14] The time available for actions is identified in Figure 5-1 as T_{avail}.

Table 5-3
In-MCR actions HEP lookup tables

HEP Lookup Table	Time Margin	HEP*	HEP Label
A	≥100%	0.005	INCR2
	50–99%	0.025	INCR3
	<50%	1.0	INCR4
B	≥100%	0.025	INCR5
	50–99%	0.125	INCR6
	<50%	1.0	INCR7
C	≥100%	0.001	INCR8
	50–99%	0.005	INCR9
	<50%	1.0	INCR10
D	≥100%	0.005	INCR11
	50–99%	0.025	INCR12
	<50%	1.0	INCR13
E	≥100%	0.05	INCR14
	50–99%	0.25	INCR15
	<50%	1.0	INCR16
F	≥100%	0.1	INCR17
	50–99%	0.5	INCR18
	<50%	1.0	INCR19
G	≥100%	0.2	INCR20
	<100%	1.0	INCR21
H	≥100%	0.25	INCR22
	<100%	1.0	INCR23
I	≥100%	0.5	INCR24
	<100%	1.0	INCR25
J	≥100%	0.01	INCR26
	50–99%	0.05	INCR27
	<50%	1.0	INCR28

Table 5–3
In-MCR actions HEP lookup tables (continued)

HEP Lookup Table	Time Margin	HEP*	HEP Label
K	≥100%	0.02	INCR29
	50–99%	0.1	INCR30
	<50%	1.0	INCR31
L	≥100%	0.04	INCR32
	50–99%	0.2	INCR33
	<50%	1.0	INCR34
M	≥100%	0.05	INCR35
	50–99%	0.25	INCR36
	<50%	1.0	INCR37
N	≥100%	0.1	INCR38
	50–99%	0.5	INCR39
	<50%	1.0	INCR40
O	≥100%	0.2	INCR41
	<100%	1.0	INCR42

*Note: HEPs provided may show multiple significant digits; these are provided to show traceability between the resulting number and the multipliers used and are not intended to imply a level of precision beyond a single significant digit. The analyst is welcome to round the values to one significant digit in the analysis.

The termination point of the branch of the flowchart will direct the analyst to the correct row in the HEP lookup table column in Table 5-3. The second column lists the time margins available for selection by the analyst based on the calculation of the time margin for the action. The next column provides the HEP value. Finally, the last column gives the label to use for identifying how the HEP was assigned.

5.2.7 Guidance for Using the EXCR Flowchart for Ex-CR Actions

The flowchart presented in Figure 5-4 (EXCR) assigns scoping HEPs to actions that are diagnosed within the MCR but must be executed locally. As with the MCR action flowchart (Figure 5-3, INCR), this flowchart is intended to be used for new HFEs identified outside the internal events PRA or existing HFEs from the internal events analysis.

In general, the EXCR flowchart (Figure 5-4) is similar to the INCR flowchart (Figure 5-3). The additional pieces of information that will be needed beyond those necessary for the INCR flowchart (according to the guidance in Section 5.2.6) include the following:

- A determination of whether the area for the ex-CR action is accessible (D26). If it is not, credit for the action cannot be taken.
- A determination of whether the action must take place in the direct vicinity of the fire (D26). If the answer is "yes," credit for the action cannot be taken.
- An estimate of the effects of the expected levels of smoke and other hazardous elements in the areas in which the action must take place (D29, D30, D34, and D37).

Other than answering these questions, analysts will step through the flowchart for ex-CR actions (Figure 5-4; EXCR) just as was done for MCR actions in the flowchart in Figure 5-3 (INCR). Lookup tables for the ex-CR flowchart are provided in Table 5-4 (see the guidance in Section 5.2.6 for the use of the lookup tables).

Table 5-4
Ex-CR actions HEP lookup tables

HEP Lookup Table	Time Margin	HEP*	HEP Label
P	≥100%	0.01	EXCR6
	50–99%	0.05	EXCR7
	<50%	1.0	EXCR8
Q	≥100%	0.05	EXCR9
	50–99%	0.25	EXCR10
	<50%	1.0	EXCR11
R	≥100%	0.002	EXCR12
	50–99%	0.01	EXCR13
	<50%	1.0	EXCR14
S	≥100%	0.01	EXCR15
	50–99%	0.05	EXCR16
	<50%	1.0	EXCR17
T	≥100%	0.5	EXCR18
	<100%	1.0	EXCR19

Table 5-4 (continued)
Ex-CR actions HEP lookup tables

HEP Lookup Table	Time Margin	HEP*	HEP Label
U	≥100%	0.1	EXCR20
	50–99%	0.5	EXCR21
	<50%	1.0	EXCR22
V	≥100%	0.2	EXCR23
	<100%	1.0	EXCR24
W	≥100%	0.4	EXCR25
	<100%	1.0	EXCR26
X	≥100%	0.02	EXCR27
	50–99%	0.1	EXCR28
	<50%	1.0	EXCR29
Y	≥100%	0.04	EXCR30
	50–99%	0.2	EXCR31
	<50%	1.0	EXCR32
Z	≥100%	0.08	EXCR33
	50–99%	0.4	EXCR34
	<50%	1.0	EXCR35
AA	≥100%	0.1	EXCR36
	50–99%	0.5	EXCR37
	<50%	1.0	EXCR38
AB	≥100%	0.2	EXCR39
	<100%	1.0	EXCR40
AC	≥100%	0.4	EXCR41
	<100%	1.0	EXCR42

*Note: HEPs provided may show multiple significant digits; these are provided to show traceability between the resulting number and the multipliers used and are not intended to imply a level of precision beyond a single significant digit. The analyst is welcome to round the values to one significant digit in the analysis.

5.2.8 Guidance for Using the ASD Flowchart for Alternate Shutdown Actions

The flowchart presented in Figure 5-5 (ASD) provides analysts with a way to obtain HEPs for the actions associated with the use of alternate shutdown. The actions quantified through the use of this flowchart are those in which command and control are located outside the MCR (i.e., diagnosis of the action, coordination of efforts, and communication occur outside the MCR). Factors impacting the qualitative analysis of alternate shutdown are provided in Section 4.8. The following information will be needed to conduct the scoping quantitative analysis (following the guidance in Section 5.2.5.1):

- The identification of the cues necessary for diagnosing the needed actions and whether the instruments supporting the necessary cues have been verified to be protected from the fire effects (D40).
- A determination of whether the procedures related to **diagnosing** the action will generally match the expected pattern of cues for a given scenario (D41).
- The availability of procedures to support the **execution** of the action or documentation that the action can be considered skill-of-the-craft (D42).
- A determination of whether the area for the ex-CR action is accessible (D43). If it is not, credit for the action cannot be taken.
- A determination of whether the action must take place in the direct vicinity of the fire (D43). If the answer is “yes,” credit for the action cannot be taken.
- A determination of the available time from when the cue for the action occurs until the response is no longer beneficial. If the time available for an action is approximately ≤30 minutes as opposed to >30 minutes, different paths are taken through the flowchart (D44).
- The level of execution complexity expected; high or low indicates different paths (D45 and D49).
- An estimate of the effects of expected levels of smoke and other hazardous elements in the areas in which the action must take place (D47, D48, and D50–D55); for example, whether SCBAs will need to be worn.

With this information, analysts will be able to step through the decision flowchart for alternate shutdown actions and, in most cases, obtain HEPs useable for HFEs involving actions taken after command and control has been switched to outside the MCR.

Upon initiating the steps in this flowchart, the first questions ask whether the necessary cues for the action have been verified to be protected from the effects of the fire (D40) and whether the scenario matches the procedures (D41). If the answer to either is “no,” the action is assumed to fail (HEP = 1.0). If the answer to both is “yes,” it is asked whether either of the following applies:

- Procedures are available to support executing the action outside the MCR.
- The action (and related subtasks) can be assumed to be skill-of-the-craft and therefore not requiring step-by-step procedures (D42).

If neither of these options is true, the action is assumed to fail (HEP = 1.0). If one of the options can be assumed, the analyst continues in the flowchart and addresses the area in which the action(s) will be taken as well as the path to the target location (D43). If neither the area nor the path to the area is accessible, the action is assumed to fail (HEP = 1.0). If the area and path are

accessible, quantification continues similar to those steps taken for ex-CR and MCR actions in which the action time window is measured, the execution complexity assessed, and the need for SCBA is determined.

The lookup tables for the alternate shutdown flowchart are presented in Table 5-5. In determining the time margin to use in the quantification of the actions, the analyst must take into account timing issues important to alternate shutdown (e.g., the time required to perform a switchover to an ASP or ASD strategy or the additional time required to perform what were formerly in-MCR actions outside the MCR).

Table 5-5
Alternate shutdown actions HEP lookup tables

HEP Lookup Table	Time Margin	HEP*	HEP Label
AD	≥100%	0.2	ASD9
	<100%	1.0	ASD10
AE	≥100%	0.4	ASD11
	<100%	1.0	ASD12
AF	≥100%	0.8	ASD13
	<100%	1.0	ASD14
AG	≥100%	0.04	ASD15
	50–99%	0.2	ASD16
	<50%	1.0	ASD17
AH	≥100%	0.08	ASD18
	50–99%	0.4	ASD19
	<50%	1.0	ASD20
AI	≥100%	0.16	ASD21
	50–99%	0.8	ASD22
	<50%	1.0	ASD23
AJ	≥100%	0.2	ASD24
	<100%	1.0	ASD25
AK	≥100%	0.4	ASD26
	≤100%	1.0	ASD27
AL	≥100%	0.8	ASD28
	<100%	1.0	ASD29

*Note: HEPs provided may show multiple significant digits; these are provided to show traceability between the resulting number and the multipliers used and are not intended to imply a level of precision beyond a single significant digit. The analyst is welcome to round the values to one significant digit in the analysis.

Of particular importance is the consideration of the time required for the conditions to reach a state in which the crew would need to use alternate shutdown, that is, the time it would take for the MCR to become uninhabitable (see criteria from Section 11.5.2 of NUREG/CR-6850 [1]) or the time it would take to reach a state in which the plant could no longer be controlled (or adequately controlled) from the MCR because of fire effects (see NUREG/CR-6776 [12] for information relevant to determining such timing). These times will have to be factored into the analysis. They may also affect assumptions about which operator actions would be performed in the control room prior to using alternate shutdown methods and which automatic system actuations would have occurred. In general, it can be assumed that there would be adequate time for most "immediate emergency operator actions" to be accomplished before the crew has to switch to the alternate shutdown.

Even if the crews do not fully abandon the control room, as long as they have switched to alternate shutdown (command and control outside the MCR), additional timing issues must be considered. An estimate of the time required before the fire might significantly affect plant control from the MCR (see NUREG/CR-6776 [12]) can be used as the estimate of when the crew would need to switch plant control to alternate methods. This time may be inaccurate: some crews may anticipate the need to switch to alternate shutdown and do it earlier; others may be reluctant and stay longer. However, the assumption made will have to be based on the plant-specific analysis and consideration of PSFs (see Section 4). In quantifying human actions that will need to occur after the decision to use alternate shutdown has been made, the time required to set up or switch over to an ASP or use other alternate shutdown methods will have to be taken into account. This time would need to be subtracted from the time available to perform the remaining actions.[15]

Two other issues also arise. If there is reason to believe that the crews would switch to alternate shutdown early, the potential difficulties associated with performing the remaining actions outside the MCR would have to be taken into account in their quantification. Similarly, if there is reason to believe that the crews would switch sometime after the point at which control would be lost or the MCR would be assumed to be uninhabitable, this time would have to be subtracted from the available time (as noted previously). Furthermore, credit could not be taken for completing any critical actions in the MCR after the time estimated for when control relevant to those actions could be lost.

5.2.9 Guidance for Using the SPI Flowchart for EOC or EOO Resulting from Spurious Instrumentation

The flowchart presented in Figure 5-6 (SPI) addresses the assignment of HEPs for the failure to recover an EOC or EOO committed as a response to misleading cues or damaged or spurious instrumentation because of fire effects. Response may be to a single or to multiple spurious indicators, but the assumption in both cases is that an error (EOC or EOO) has already occurred. (Note that Section 4.10 goes into greater detail about the complexity involved with identifying

[15] Analysts are encouraged to perform plant-specific analyses and strive to make reasonable estimates of the timing of events based on the guidance in this report; however, trying to precisely anticipate when operating crews will decide to abandon the MCR (for example) in these conditions may not always be realistic. It is assumed that operating crews will respond to the conditions they face and take necessary steps to reach safe shutdown. The use of time margins and the general conservatism of the scoping approach are assumed to adequately account for potential imprecision in estimating the related timing.

and addressing multiple spurious indicators and operations). Upon initiating the steps in the flowchart, it is assumed that the EOC or EOO has been committed (i.e., an HFE has been modeled to address the potential error); the flowchart then assesses the probability that this error would remain uncorrected (i.e., operator recovery of the EOO or EOC fails).

As discussed in Sections 4.3 and 5.2.5.2, a *primary cue* is defined as the first cue received and responded to. A *cue* is a signal or alert (i.e., plant parameter, procedure step, or plant condition) that prompts an operating crew to take a specific action. A *secondary cue* is one that occurs after the primary cue or in conjunction with the primary cue but is acknowledged only for verification of the primary cue.

To quantify the recovery of EOCs or EOOs resulting from spurious instrumentation with the scoping fire HRA approach (i.e., go beyond the 1.0 HEP value set with the screening approach), the HRA analyst must know the cable routing for the spurious instrumentation in question. If the instrumentation (e.g., level in the reactor pressure vessel or steam generator) is required for a fire manual action, the cable routing may be known prior to fire PRA analysis. In many cases, the fire procedures specifically indicate which trains of instrumentation (identified as *protected* or *available* by the fire protection program) are available given the location of the fire.

However, there are HFEs required for fire PRA that are not required for the deterministic safe shutdown analysis (Appendix R [10] or NFPA 805 [11]), for example, the operator action for switching over to recirculation. In this case, the cable tracing for RWST level indicators will need to be obtained to credit this action. If the cables for RWST level indication are routed through the fire area in question, EOOs and EOCs resulting from spurious indicators need to be considered. If the cables are not routed through this room, EOOs and EOCs do not need to be considered. If the instrumentation is not required for a deterministic safe shutdown action, it can be assumed that it is not protected by an ERFBS.

Some instruments and cues associated with safety systems—in particular, those associated with achieving and maintaining safe shutdown conditions—are considered “protected” in accordance with 10 CFR Part 50 Appendix R or NFPA 805. However, even if the equipment and cables are protected according to the deterministic safe shutdown analysis criteria, it will need to be verified that the likely nature and location of the fire in a given area would not damage the cables (e.g., due because of direct flame impingement or explosive fires). If a cue can be verified to be protected such that a spurious indicator would not result, there is no need to model the EOC or EOO.

Furthermore, some plants offer a list of equipment and indications that, based on the specific fire location(s), can be regarded as “suspect.” For this scoping fire HRA guidance, if a plant has such a list to be used in fire scenarios, it can be assumed that the operating crew is “suspicious” of a listed spurious indication (or a spurious equipment actuation) if it appears during the appropriate fire scenario. Therefore, the analyst does not need to model the response to spurious indicators for situations in which the instrument in question is listed as being suspect because of the location of the fire. If, however, the HRA analyst believes that other circumstances might cause the operator to ignore this warning and might commit the error regardless (e.g., time pressure, real or inferred, keeping the operator from verifying the suspect instrument), the analyst may still model the action as if an EOC or EOO has occurred.

Following the assumption that the operator would commit an EOC or EOO because of a spurious indicator, Figure 5-6 quantifies the probability of recovering this error. The initial question asked upon beginning the steps in Figure 5-6 is whether information is available to help the operators recognize the need to recover the error (D56). Recovery of the error may be through either of the following:

- For the committal of an EOC, reversal of the action or the use of an alternative system
- If an EOO has been committed, performance of the necessary action

The indications directing the operator to the need to recover may be through procedural guidance or through subsequent (in particular, different) cues or the contextual information informing the operator that an error has been made (e.g., if operators have turned off a needed pump to protect it because of a spurious alarm, it is reasonable to expect that they would recognize the need to replace the function given the context). If procedural guidance is not available, the contextual information or subsequent cues must be strong enough (i.e., compelling) to make the operator aware that the situation must be remedied (e.g., a compelling alarm). This is particularly true if the operator was following procedural guidance when responding to the spurious indicator. It will naturally be the operator's predilection to believe that the action was necessary and not question further. Therefore, the cues (either existing diverse cues or subsequent cues) must raise a suspicion in the operator to more carefully consider the situation and turn to recovery actions. If the guidance or cues do not exist and make the operator aware of the need to remedy the situation—either by recognizing that an error has been made or recognizing the need for the function or action—the recovery action is assumed to fail (i.e., HEP = 1.0).

After it is decided that recognition for recovery is present, the methods for recovery should be evaluated. Although the operator may recognize that the error needs to be corrected or that the function needs to be started, restored, or recovered, doing so may not be possible. Therefore, the availability and feasibility of the recovery action should be ensured before progressing further (D57).

Given that the recovery action can be performed, the next decision point is the location of the action (D58). If the action is performed within the MCR, the analyst is pointed in one direction in the flowchart and is pointed in the other direction if the action is local. At this point, the quantification proceeds as was done in the quantification of in-MCR actions (Figure 5-3) and ex-CR actions (Figure 5-4). For MCR actions, a series of questions is asked to determine the time required and the time available; the level of execution complexity; the level of smoke, heat, or other toxins; and the need to wear SCBA. For more discussion on how each of these is considered, see Section 5.2.3.

For ex-CR actions, the first issue is to ensure that both the area in which the action takes place and the travel path to the area are accessible (D68). If this is not the case, the action is assumed to fail (HEP = 1.0). Assuming that the area and travel path are accessible, the analyst must work through a series of questions similar to those asked for MCR actions. Specifically, the analyst needs to determine the time required and the time available; the level of execution complexity; the level of smoke, heat, or other toxins at the site of the action; and the need to wear SCBA.

Depending on the response to each of the questions posed in the flowchart, the action will either immediately be assigned an HEP of 1.0 or the analyst will be directed to an HEP lookup table. The lookup tables for the SPI flowchart are provided in Table 5-6. From there (in the HEP lookup table), the analyst is directed to the appropriate HEP based on the time margin associated with the action.

Table 5-6
EOC or EOO resulting from spurious instrumentation HEP lookup tables

HEP Lookup Table	Time Margin	HEP*	HEP Label
AM	≥100%	0.25	SPI11
	<100%	1.0	SPI12
AN	≥100%	0.5	SPI13
	<100%	1.0	SPI14
AO	≥100%	0.05	SPI15
	50–99%	0.25	SPI16
	<50%	1.0	SPI17
AP	≥100%	0.1	SPI18
	50–99%	0.5	SPI19
	<50%	1.0	SPI20
AQ	≥100%	0.2	SPI21
	<100%	1.0	SPI22
AR	≥100%	0.25	SPI23
	<100%	1.0	SPI24
AS	≥100%	0.5	SPI25
	<100%	1.0	SPI26
AT	≥100%	0.1	SPI27
	50–99%	0.5	SPI28
	<50%	1.0	SPI29
AU	≥100%	0.2	SPI30
	<100%	1.0	SPI31

Table 5–6
EOC or EOO resulting from spurious instrumentation HEP lookup tables (continued)

HEP Lookup Table	Time Margin	HEP*	HEP Label
AV	≥100%	0.4	SPI32
	<100%	1.0	SPI33
AW	≥100%	0.5	SPI34
	<100%	1.0	SPI35
AX	≥100%	0.5	SPI36
	<100%	1.0	SPI37

*Note: HEPs provided may show multiple significant digits; these are provided to show traceability between the resulting number and the multipliers used and are not intended to imply a level of precision beyond a single significant digit. The analyst is welcome to round the values to one significant digit in the analysis.

5.3 Detailed HRA Quantification

Before quantifying an HFE, the analyst must have applied the criteria discussed in Section 4.3 for assessing the feasibility of the operator action(s) associated with that HFE. Although the feasibility assessment process begins at the identification and definition stage and is a key part of the initial qualitative analysis, new information may be available during the quantification process that would require the feasibility to be reassessed. Therefore, feasibility assessment is a continuous action step throughout the fire HRA.

As discussed in Section 5.2, it is expected that some actions will not be able to meet some of the criteria in the scoping fire HRA approach for any of a number of reasons (and result in an HEP of 1.0). Furthermore, the HEPs developed using this approach may be fairly conservative compared to those that could be developed using one of the two detailed HRA approaches described in this report.

For cases in which the scoping method cannot be used or a more detailed and possibly less conservative analysis is desired, analysts have the option of performing a detailed analysis using either of the following:

- The EPRI HRA approach [3] presented in Appendix B of this report
- The ATHEANA HRA method [4, 5] presented in Appendix C

With appropriate consideration of the fire context as described in Section 4, Qualitative Analysis, and specific consideration of PSFs as determined by the methods, the two detailed HRA methodologies presented can be used to address fire-specific issues and PSF impacts.

Additional guidance on method selection (given the fire context) is desirable but not available at this time. At present, the method selected for detailed quantification will be based on considerations such as plant-specific scenario information, fire context/impact, and general suitability (for non-fire conditions). NUREG/CR-1842 [13] provides general insights on the strengths and weaknesses of HRA methods for non-fire conditions.

5.4 References

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

   Note: When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following as well:

   Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.

2. 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*, The American Society of Mechanical Engineers, New York, NY, February 2009.
3. *An Approach to the Analysis of Operator Actions in Probabilistic Risk Assessment*. EPRI, Palo Alto, CA: 1992. TR-100259.
4. U.S. Nuclear Regulatory Commission. NUREG-1880, *ATHEANA User's Guide*, June 2007.
5. U.S. Nuclear Regulatory Commission. NUREG-1624, Revision 1, *Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (ATHEANA)*, May 2000.
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11. National Fire Protection Association (NFPA) Standard 805, *Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants*, 2001 Edition.
12. U.S. Nuclear Regulatory Commission. NUREG/CR-6776, *Cable Insulation Resistance Measurements Made During Cable Fire Tests*, June 2002.
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6 RECOVERY, DEPENDENCY, AND UNCERTAINTY

This section provides guidance on recovery, dependency, and uncertainty. The fundamentals of each of these steps in the HRA process are not unique to fire HRA; this section summarizes the steps with respect to both internal events and fire HRA. These are the last tasks in the fire HRA process outlined in Section 2. The other fire HRA tasks are described in Section 3, Identification and Definition; Section 4, Qualitative Analysis; and Section 5, Quantification. Of these earlier tasks, the qualitative analysis (Section 4) provides a foundation for understanding that action and the fire PRA context and is useful for the proper conduct of the recovery, dependency, and uncertainty analysis.

6.1 Recovery Analysis

A *recovery human failure event* is the failure to restore failed equipment or find alternative equipment or configurations within the time period required, as defined by Dougherty and Fragola [1]. New recovery actions are often needed for the development and evaluation of realistic fire PRA models at different stages of development (e.g., Task 7b and/or Task 11 of NUREG/CR-6850 [2]). Recovery actions are incorporated into the fire PRA models in the same way as in the internal events PRA. The ASME/ANS PRA Standard [3] Supporting Requirement HR-H2 permits the modeling of recovery actions that have cues, procedures, and training (or justification for why these are not necessary) and are feasible. It should be noted that recovery mechanisms such as peer checking, unexpected instrument responses in response to an action, and new alarms are typically credited in the initial HFE and not modeled explicitly as separate basic events in the PRA model. This section is concerned with new operator actions, typically identified by cutset review and credited in the PRA as one or more explicit basic events.

Recovery actions are identified, defined, and quantified following the same process as all other HFEs in the fire PRA model. The main difference for a fire HRA is the consideration of the impact of the fire on the ability to perform recovery actions associated with specific fire scenarios.

After the initial fire PRA model quantification, recovery actions may be identified to restore or reconfigure a function, system, or component initially unavailable in the scenario. Accounting for such a recovery would reduce the frequency of the scenario. The need for recovery actions can follow from PRA model iterations with a screening, scoping, or detailed analysis. The identification of the recovery actions includes not only the identification and definition covered in Section 3, but also a preliminary feasibility assessment consistent with that discussed in Section 4.3. Feasible recovery actions require sufficient time, a cue (instruments or procedure), and the necessary tools and staff to carry out the recovery action. Realignments, manual starts, and breaker operations are examples of recoveries that can be modeled in fault trees, event trees, or as cutset events.

The qualitative analysis of fire PRA recovery actions covers the issues and PSFs described in Section 4, and quantification is performed using the methods discussed in Section 5.

The fire PRA also considers the fire brigade and their actions to extinguish the fire. Note that NUREG/CR-6850 [2] addresses this type of recovery action in the fire modeling task through statistical models derived from fire suppression event data. Because the impact is on the fire itself, it is **not** addressed as an HRA modeling issue. Instead, a fire scenario with suppression considered is defined to include its impact on the electrical instruments, controls, and power cables to define the input conditions for the HRA models that impact the CDF PRA model.

The term *recovery action* is not a term unique to fire PRA or PRA in general—although it is an important term in NFPA 805 [4]. NFPA 805 recovery actions are documented in their own section of the plant's license amendment request; NFPA 805 defines *recovery actions* as "activities to achieve the nuclear safety performance criteria that take place outside of the MCR or outside of the primary control station(s) for the equipment being operated, including the replacement or modification of components." NFPA 805 recovery actions are a subset of fire PRA actions because fire PRA recovery actions are not specific to the execution location.

6.2 Dependency Analysis

The analysis of multiple HFEs is important because risk metrics such as CDF can be significantly underestimated in cutsets or sequences containing multiple HEPs if potential dependencies are not considered. The ASME/ANS Standard [3] requires that multiple human actions in the same accident sequence or cutset be identified, an assessment of the degree of dependency performed, and a joint human error probability be calculated. For fire PRA, a preliminary dependency analysis is performed in combination with NUREG/CR-6850 [2], Detailed Fire Modeling Task 11, and is finalized as part of Task 14, Fire Risk Quantification.

A dependency assessment of the applicable HFEs in the internal events PRA has been performed according to the ASME/ANS PRA Standard [3] to ensure that the dependencies are accounted for in the fire PRA. Potential dependencies created either by the fire effects or by the associated introduction of new HFEs into the model also need to be addressed. If new HFEs related to the fire have been added to the model, these new actions should be shown to not create new dependencies among the HFEs in the accident sequence. In addition, any likely strong dependencies should be shown to be accounted for during the screening so that accident sequences/cutsets are not artificially removed because of multiplying many supposedly independent HEPs together.

This section is concerned with the identification of dependencies among post-initiator HFEs at the cutset level that have so far been quantified as independent HFEs. The identification and qualitative analysis steps may also identify relationships (often referred to as *dependencies*) among PSFs. The relationships among multiple PSFs within a single HFE are addressed in scoping or detailed HRA quantification.

A review of the cutsets for dependencies will show some combinations in which both screening and scoping HEPs exist. The screening HEPs, by definition, are considered conservative; further adjusting these HEPs may either increase the HEP to 1.0 or make them overly and unrealistically conservative. The screening HEPs will not usually need to be further adjusted to account for dependencies as long as the combination of operator actions is shown to be feasible (i.e., there are enough time and available crew members to complete all of the actions).

Scoping HEPs can be treated using the same approach as described in the following section, but the criteria for the scoping HEPs must still be met. That is, if credit for the action is taken, the adjustments in the HEPs should still reflect both that the actions are feasible and that there is an adequate time margin given the dependent effects.

Through a review of cutsets and sequences, combinations of multiple sets of HFEs are identified for potential dependencies. This review can be facilitated by conducting a sensitivity analysis that sets the HFEs to a high value, such as 0.9 or 1.0, to allow them to surface in the cutsets. When the cutsets or sequences are identified, they should be reviewed as follows:

- The review should ensure that no accident sequences with multiple human actions were prematurely truncated.
- An assessment of the feasibility of multiple operator actions performed within the same sequence should be performed. For fire PRA, there is the potential for several fire response actions to be performed within the same sequence. If feasibility has been demonstrated for the operator action as an independent action—which could be the case if it is a fire manual action—there is the potential that insufficient crew will be available to perform all actions in the sequence. In addition, there may be enough time to perform each action independently; however, in combination, not enough time is available.

For HRA, it is important to not only identify failure HFEs in the sequence, as would be the case in a review of the cutsets, but also to review successful operator actions that occur in the same sequence. The success paths would be identified through a review of the event trees and should be noted in the HFE definition in accordance with the ASME/ANS PRA Standard Supporting Requirement HR-F2 [3].

Where it is found that combinations of operator actions HEPs are unduly multiplied in the cutsets, the appropriate level of dependency among the HEPs is to be assessed. In accordance with the ASME/ANS PRA Standard, influences of success or failure on parallel and subsequent human actions and system performance should include the following:

- The time required to complete all actions in relation to the time available to perform the actions
- Factors that could lead to dependence (e.g., common instrumentation or procedures, an inappropriate understanding or mindset as reflected by the failure of a preceding HFE, and increased stress)
- The availability of resources (e.g., crew members and other plant personnel to support the performance of ex-CR actions)

When a combination of HFEs is identified, a level of dependency is assigned. One approach to assigning a level of dependency is shown in Figure 6-1 [5]. Table 6-1 translates the level of dependency into the conditional probability of the second HFE given that the first HFE has failed. Both internal events HRA and fire HRA evaluate the same elements in the dependency analysis.

Figure 6-1
Dependency rules for post-initiator HFEs

Note: The units of the "Sequential Timing" branch are in minutes.

The following elements are evaluated in the dependency analysis:

- **Intervening Success.** In accordance with THERP [6], an HFE is independent of an immediately preceding success. Therefore, if two HFEs are identified in a cutset and a successful action can be identified between the two HFEs, the two HFEs in that cutset are considered independent.
- **Crew**. If the time between the cues for the required actions exceeds the length of a shift (typically 12 hours), the actions are to be performed by a different crew. In this case, the "No" branch on the "Crew" decision node is selected. The different crew can be considered independent because the shift change will involve a complete reevaluation of the plant status, so *ZD* can be assigned for low stress situations (Branch 18). For elevated stress such as a fire, *LD* is assigned. If the time between the cues is less than the length of a shift, the probability of a shift change during the time window needs to be considered. For a typical HFE time window of 1 hour and a shift length of 12 hours, the probability of no shift change is 1-(1/12) = 0.92, so HFEs by different crew are typically only credited in scenarios in which the HFE time window is longer than the length of a shift.
- **Cognitive.** If the HFEs have a common cognitive element (i.e., performed by the same crew and driven by the same cue or procedural step), the "Yes" branch on the "Cognitive" decision node is selected as a first approximation—because these HFEs would be regarded as completely dependent. The analyst should determine whether the common cognitive element had been modeled as a separate basic event. If it has, the "No" branch can be selected.
- **Cue Demand.** If the cues for two HFEs occur at the same time, the "Yes" branch on the "Cue Demand" decision node is selected. The required actions for these HFEs are to be performed simultaneously. If the cue for subsequent action occurs before the preceding action can be completed (as shown in Figure 6-2), the "Yes" branch on the "Same Time" decision node is also selected because the required actions would have to be performed simultaneously or the crew may choose to do either one or the other based on some prioritization. These HFEs are termed *simultaneous HFEs*.

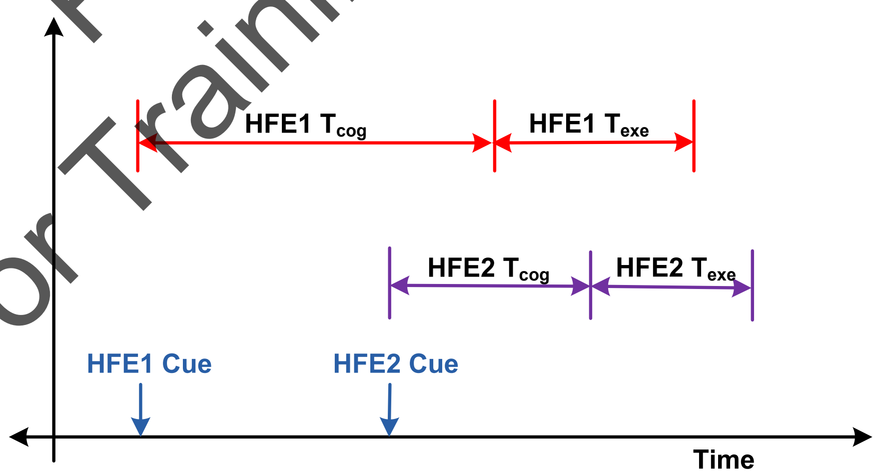


Figure 6-2
Simultaneous HFEs

- **Manpower.** For simultaneous HFEs, the next consideration is whether there are sufficient resources to support the required actions. This determination can be made by comparing the required tasks with the number of crew available. If the resources are inadequate, the "No" branch on the "Manpower" branch is selected, which implies complete dependence. If it can be shown that there are adequate resources to support both HFEs **and** that the scenario is feasible, the "Yes" branch on the "Adequate Resources" branch is selected. Next, location and stress are considered. For the same location, the "Yes" branch on the "Location" decision node is selected. For high or moderate stress scenarios, assign complete dependence; for low stress, assign high dependence. For different locations, the "No" branch on the "Location" decision node is selected. For high or moderate stress scenarios, assign moderate dependence; for low stress, assign low dependence.
- **Location.** Location refers to the room or general area in which the crew members are located. For example, the control room is a location; location is not differentiated down to individual panels in the control room. If the execution of the HFEs occurs in the same location, the dependency level is either high or complete; if the actions are performed in different locations, the dependency level is either moderate or low.
- **Sequential Timing.** This timing decision branch considers the time between the cues. The more time between the cues, the lower the dependency level.
- **Stress.** Stress is a culmination of all other performance shaping factors. These factors may include preceding functional failures and successes, preceding operator errors or successes, the availability of cues and appropriate procedures, workload, environment (i.e., heat, humidity, lighting, atmosphere, and radiation), the requirement and availability of tools or parts, and the accessibility of locations. In general, stress is considered high for loss-of-support-system scenarios or when the operators need to progress to functional restoration or emergency contingency action procedures. The higher the stress level, the higher the dependency level.

With the proper level of dependency identified, the dependent HEPs can be reassessed by applying the appropriate dependency formulas in Table 10-17 in THERP [6], shown here in Table 6-1.

Table 6-1
THERP dependency equations

Dependence Level	Equation	Approximate Value for Small HEP
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

Some HRA methods, such as ATHEANA, use a different approach to address dependencies. For example, ATHEANA [7, 8] explicitly models both the initial HFE and the non-recovery event together, on a cutset-by-cutset basis. Failure probabilities of post-initiator HFEs that occur after the first HFE in an accident sequence are evaluated as conditional probabilities given the context of the preceding HFEs, the initial scenario context, and any subsequent context elements.

NUREG-1792 [9] and EPRI 1021081 [10] address the need to consider a minimum value for the joint probability of multiple HFEs. The following is stated in NUREG-1792:

> The resulting joint probability of the HEPs in an accident sequence should be such that it is in line with the above characteristics [which are the conditions under which the operator actions may be dependent] and the following guidance, unless otherwise justified:
>
> The total combined probability of all the HFEs in the same accident sequence/cut set should not be less than a justified value. It is suggested that the value not be below ~1E-05 since it is typically hard to defend that other dependent failure modes that are not usually treated (e.g., random events such as even a heart attack) cannot occur. Depending on the independent HFE values, the combined probability may need to be higher.

EPRI 1021081 recognizes this statement in NUREG-1792 and goes on to address the issue further in the following discussion:

> NUREG-1792 introduces formally the concept of a limiting value on the combined HEP, and the use of such a value is widely regarded as being expected in regulatory applications. While it may not have been intended as an absolute limit, but more as a sort of trigger, to have the analyst check lower joint HEPs to see if some underlying dependence had been overlooked, it has often been interpreted as absolute.
>
> When a limiting value for the combined HEP for a group of HFEs is proposed, it would be applied when the prescribed approach for dealing with dependency results in a total combined HEP that is less than that limiting value. A strict application of the guidance from NUREG-1792 above would be to apply the limiting value even if the HFEs were considered to be independent according to the criteria the analyst has adopted for determining the degree of dependence or independence.
>
> This has caused difficulty in applying the Significance Determination Process (SDP) of the NRC's Reactor Oversight Process, particularly for shutdown events, where operator action is usually an important part of the response, and where the initiating event may have been due, to some extent, to human action. Using a minimum value of 1×10^{-5} has resulted in findings that would otherwise have characterized an event or condition as having very low risk becoming "white" findings.
>
> Therefore, while it might be reasonable to adopt some sort of limit, it needs to be done carefully, so that the results of PRAs are not distorted by arbitrary assignments of probabilities. As discussed in detail later on, any limiting values should be consistent within the context of the scenarios in which they are applied.

For fire HRA, it is recommended that the application of a lower bound follow the same guidance as was applied to the internal events PRA.

6.3 Uncertainty Analysis

For fire HRA, uncertainties should be addressed in the same manner as for internal events HRA. Therefore, similar to the internal events HRA/PRA, assumptions are one source of uncertainty for fire HRA. Other sources of uncertainty include timing assessments or selections of performance shaping factors.

Table 6-2 lists potential sources of fire HRA modeling uncertainty based on experience and on results of fire HRAs performed by the authors. Other plant-specific fire HRA applications might have different sources of modeling uncertainty; this list is therefore not all-inclusive.

Table 6-2
Potential sources of fire 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.

The application of an error factor or other distribution uncertainty measure to a fire PRA screening or scoping HEP is not considered appropriate because these values are intended to be conservative estimates representing a higher, bounding HEP. It should be noted, however, that there may be specific cases in which the scoping and screening HEPs are not conservative with respect to internal events HRA values; in those instances, some consideration of the uncertainty surrounding these values might be desirable.

The ATHEANA HRA method [7, 8] addresses uncertainty analysis more directly. In particular, if the full expert elicitation approach for quantification is used in ATHEANA, uncertainty distributions for HFEs are produced as part of the quantification process.

Active research is ongoing in the area of uncertainty analysis, and the topic is still evolving. The following references are applicable to uncertainty analysis for internal events HRA and should also be considered for fire HRA:

- NUREG-1855 [11]
- EPRI 1009652 [12]
- NUREG-1792 [9]
- NUREG/CR-1278 [6]

6.4 References

1. Dougherty, E. M. and Fragola, J. R., *Human Reliability Analysis: A Systems Engineering Approach with Nuclear Power Plant Applications*, John Wiley & Sons, 1988.
2. U.S. Nuclear Regulatory Commission. NUREG/CR-6850, EPRI 1011989, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities.* September 2005.

   Note: When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following as well:

   Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.
3. 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*, The American Society of Mechanical Engineers, New York, NY, February 2009.
4. National Fire Protection Association (NFPA) Standard 805, *Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants*, 2001 Edition.
5. "HRA Dependency Analysis Using the EPRI HRA Approach," J. A. Julius, J. F. Grobbelaar, and K. D. Kohlhepp, Scientech, a Curtiss-Wright Flow Control company, Paper presented at ESREL Conference 2010.
6. U.S. Nuclear Regulatory Commission. NUREG/CR-1278, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications" (THERP)*, Swain, A. D. and Guttman, H. E., August 1983.
7. U.S. Nuclear Regulatory Commission. NUREG-1624, Revision 1, *Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (ATHEANA)*, May 2000.
8. U.S. Nuclear Regulatory Commission. NUREG-1880, *ATHEANA User's Guide*, June 2007.
9. U.S. Nuclear Regulatory Commission. NUREG-1792, *Good Practices for Implementing Human Reliability Analysis (HRA)*, 2005.

10. *Establishing Minimum Acceptable Values for Probabilities of Human Failure Events, Practical Guidance for Probabilistic Risk Assessment: Interim Report.* EPRI, Palo Alto, CA: 2010. 1021081.

11. U.S. Nuclear Regulatory Commission. NUREG-1855, *Guidance on Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making*, March 2009.

12. *Guideline for Treatment of Uncertainty in Risk-Informed Applications*. EPRI, Palo Alto, CA: 2005. 1009652.

7 DOCUMENTATION

In accordance with NUREG/CR-6850 [1], the output of this entire task is a calculation package (file or document). Based on the various requirements of the ASME/ANS PRA Standard [2], this package should contain the following:

- Event name, description, and resulting HEP of each HFE considered in the fire analysis, including internal events HFEs carried over to the fire PRA and recovery actions
- Description of the processes used to identify, characterize, and quantify post-initiator and recovery actions considered in the fire PRA, including the inputs, PSFs, methods and tools, and results
- The method and treatment of dependencies for post-initiator and recovery actions
- Discussion of the sources of model and quantification uncertainty and related assumptions as well as the sensitivity of the PRA risk measures to these assumptions and uncertainties
- Review of the post-initiator HEPs to ensure consistency among them and reasonableness considering contextual issues
- Disposition of the peer review exceptions and deficiencies for the internal events PRA (i.e., how they were addressed, including a determination that they did not adversely affect the fire PRA model development)
- Sufficient documentation to facilitate applications, upgrades, and peer review

The documentation of the fire HRA must be sufficient to provide traceability of the analysis from the identification and definition phase through to the quantification. For example, if walk-throughs are conducted with operations and training personnel, documentation of these sessions should be provided, equipment to be actuated, and tools to be used for the HFEs evaluated. Photo-documentation of locations to be accessed should be considered. The final table of HEP results should match the output from the HRA calculation tool or method (such as EPRI HRA Calculator file information) and the input included in the fire PRA model. Thorough documentation facilitates future updates of the analysis and provides a sound basis for the analysis so that it can withstand the scrutiny of a peer review. A pre–peer review self-assessment against the ASME/ANS PRA Standard [2] supporting requirements relevant to fire HRA, as indicated in Appendix D of this report, is recommended so that the documentation can be updated as needed to meet the requirements.

In some cases the HRA calculation tool or method may generate supporting documentation. This documentation alone (i.e., the EPRI HRA Calculator information file) is usually not sufficient as stand-alone documentation for the full HRA. Table 7-1 shows an example outline for a fire HRA report.

Table 7-1
Example fire HRA report outline

1.0	PURPOSE
2.0	SCOPE
3.0	REFERENCES
4.0	FIRE HRA PROCESS
4.1	IDENTIFICATION AND DEFINITION
4.1.1	Internal Events PRA Operator Actions
4.1.2	Fire Response Operator Actions
4.1.3	HFEs Corresponding to Undesired Operator Responses to Spurious Instrumentation or Spurious Actuations
4.2	QUALITATIVE ANALYSIS AND PRELIMINARY FEASIBILITY ASSESSMENT
4.2.1	Context Information
4.2.2	Performance Shaping Factors
4.2.3	Preliminary Feasibility Assessment
4.3	QUANTITATIVE ANALYSIS
4.3.1	Screening Analysis
4.3.2	Scoping Analysis
4.3.3	Detailed Analysis
4.3.4	Recovery Analysis
4.3.5	Dependency Analysis
4.3.6	Main Control Room Evacuation
5.0	RESULTS: HEP VALUES FOR FIRE PRA MODEL
6.0	ASSUMPTIONS AND UNCERTAINTIES
ATTACHMENT 1, REVIEWER COMMENTS/RESOLUTIONS	
ATTACHMENT 2, FIRE HRA FILES	
ATTACHMENT 3, DETAILED FEASIBILITY ASSESSMENT	
ATTACHMENT 4, MAIN CONTROL ROOM EVACUATION AND SAFE SHUTDOWN ANALYSIS	

7.1 References

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

   Note: When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following as well:

   Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.

2. 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*, The American Society of Mechanical Engineers, New York, NY, February 2009.

APPENDIX A
DEFINITION OF TERMS[16]

Accident sequence. A representation in terms of an initiating event followed by a sequence of failures or successes of events (such as system, function, or operator performance) that can lead to undesired consequences, with a specified end state (e.g., core damage or large early release).

Adversely affect. In the context of fire PRA, to impact—through fire—plant equipment items and cables leading to equipment or circuit failure (including spurious operation of devices).

Aleatory uncertainty. An uncertainty resulting from inherent randomness or stochastic process. Such uncertainties are irreducible: regardless of the level of knowledge, some unpredictability in the variable of interest still exists.

Automatic trip. Reactor trip initiated by an automatic signal from plant reactor protection systems (RPS) in response to off-normal conditions. (In the context of fire PRA, this could be a fire affecting certain plant equipment and/or circuits.)

Cable. In the context of fire PRA, the term *cable* refers to assemblies designed to conduct electrical current. Therefore, a cable is an assembly of one (single-conductor cable) or more (multi-conductor cable) insulated electrical conductors (generally copper or aluminum) that may or may not be surrounded by an outer jacket. (This definition excludes fiber-optic type cables.)

Circuit analysis. The process of identifying cables and circuits that, if damaged by fire, could prevent a fire PRA component from operating correctly.

Compartment. A generic term used to represent a room defined by four walls, a floor, and a ceiling. The boundaries may not be fire rated.

Conditional core damage probability (CCDP). The conditional core damage probability calculated by the fire PRA model. This probability is conditional on a specific fire scenario in a fire compartment postulated as a fire-induced initiating event and includes the likelihoods of the combinations of equipment failures (some may be directly induced by the fire itself) and operator failures that result in core damage. The CCDP for a given fire scenario times the frequency of that scenario results in the core damage frequency contribution for the given fire scenario.

[16] The definitions provided in this appendix have been developed, in part, by duplicating or adapting definitions from the following sources:

- ASME/ANS PRA Standard
- NUREG/CR-6850/EPRI 1011989
- 10 CFR 50, Appendix R
- Regulatory Guide 1.189

Full reference citations for these sources are given in the main body of the report.

Containment failure. Loss of integrity of the containment pressure boundary from a core damage accident that results in unacceptable leakage of radionuclides to the environment.

Core damage. Uncovery and heatup of the reactor core to the point at which prolonged oxidation and severe fuel damage involving a large fraction of the core are anticipated.

Core damage frequency (CDF). Expected number of core damage events per unit of time.

Cue. A change in condition or signal that triggers the need for an action.

Electrical Raceway Fire Barrier System (ERFBS). A rated protective fire barrier specifically designed to protect cables, cable raceways, or other equipment from external fire-induced damage.

Epistemic uncertainty. An uncertainty resulting from a lack of, or weakness in, knowledge. Such uncertainties can, theoretically, be reduced by obtaining more knowledge such as through observation of repeated trials of an event to learn the true value of the variable of interest.

Equipment. A term used to broadly cover the various components in a nuclear power plant. *Equipment* includes electrical and mechanical components (e.g., pumps, control and power switches, integrated circuit components, valves, motors, and fans) and instrumentation and indication components (e.g., status indicator lights, meters, strip chart recorders, and sensors). *Equipment*, as used in the Fire PRA Standard, excludes electrical cables.

Event tree. A logic diagram that begins with an initiating event or condition and progresses through a series of branches that represent expected system or operator performance that either succeeds or fails and arrives at either a successful or failed end state.

External event. An initiating event originating outside a nuclear power plant that causes safety system failures, operator errors, or both, that in turn may lead to core damage or large early release. Events such as earthquakes, tornadoes, and floods from sources outside the plant and fires from sources either within or outside the plant (e.g., forest fires or other wildfires) are considered external events (see also *internal event*). By convention, loss of offsite power not caused by another external event is considered an internal event.

Failure mode. A specific functional manifestation of a failure (i.e., the means by which an observer can determine that a failure has occurred) by precluding the successful operation of a piece of equipment, a cable, or a system (e.g., fails to start, fails to run, or leaks). **Note:** In the context of fire PRA, *spurious operation* (see definition following) is also considered a failure mode above and beyond failures that "preclude successful operation."

Failure probability. The likelihood that a system, structure, or component (SSC) will fail to operate on demand or for a specific mission time.

Fire area. A portion of a building or plant that is separated from other areas by rated fire barriers adequate for the fire hazard (per Regulatory Guide [RG] 1.189). (Note that a *rated fire barrier* is a fire barrier with a fire-resistance rating.)

Fire compartment.[17] A subdivision of a building or plant that is a well-defined enclosed room, not necessarily bounded by rated fire barriers. A fire compartment generally falls within a fire

[17] It is noted that the term fire compartment is used in other contexts, such as general fire protection engineering, and that the term's meaning as used here may differ from that implied in an alternative context. However, the term also has a long history of use in fire PRA and is used in this report based on that historical and common fire PRA practice.

area and is bounded by noncombustible barriers where heat and products of combustion from a fire within the enclosure will be substantially confined. Boundaries of a fire compartment may have open equipment hatches, stairways, doorways, or unsealed penetrations. This term is defined specifically for fire risk analysis and maps plant fire areas and/or zones, defined by the plant and based on fire protection systems design and/or operations considerations, into compartments defined by fire damage potential. For example, the control room or certain areas within the turbine building may be defined as a *fire compartment* (a definition derived from NUREG/CR-6850/EPRI 1011989). In the PRA Standard, *physical analysis unit* is used to represent all subdivisions of a plant for fire PRA. Physical analysis units include fire compartments.

Fire-induced initiating event. The initiating event assigned to occur in the fire PRA plant response model for a given fire scenario (adapted from NUREG/CR-6850/EPRI 1011989).

Fire modeling. As used in the PRA Standard, *fire modeling* refers to the process of exercising a fire analysis tool, including the specification and verification of input parameter values, the performance of any required supporting calculations, the actual application of the fire analysis tool itself, and the interpretation of the fire analysis tool outputs and results.

Fire PRA. The collection of analyses, computer models, and reports conducted and prepared for estimating the risk associated with fire events in a nuclear power plant.

Fire PRA component. Equipment item, system component, structural elements, and cables (power, instrumentation, and control) included as affecting the potential for core damage or large early release in the fire PRA model.

Fire PRA plant response model. A representation of a combination of equipment, cable, circuit, system, function, and operator failures or successes, of an accident that, when combined with a fire initiating event, can lead to undesired consequences with a specified end state (e.g., core damage or large early release).

Fire safe shutdown analysis. The deterministic analysis conducted often in the context of Appendix R of 10 CFR Part 50 to ensure safe shutdown capability during identified fire scenarios.

Fire scenario. A set of elements that describes a fire event. The elements usually include a physical analysis unit, a source fire location and characteristics, detection and suppression features to be considered, damage targets, and intervening combustibles.

Fire suppression system. Generally refers to permanently installed fire protection systems provided for the express purpose of suppressing fires. Fire suppression systems may be either automatically or manually actuated. However, once activated, the system should perform its design function with little or no manual intervention.

Fire zone. Subdivisions of fire areas defined in the context of the fire protection program. A fire zone is not necessarily bounded by fire barriers. Zone divisions are often defined based on the fire suppression and/or detection systems designed to combat particular types of fires. A fire zone may contain one or more rooms. A fire compartment may contain one or more fire zones.

Hot gas layer. Refers to the volume under the ceiling of a fire enclosure where smoke accumulates and high gas temperatures are observed. It is the upper zone in a two-zone model formulation.

Hot short. Individual conductors of the same or different cables coming in contact with one another, where at least one of the conductors involved in the shorting is energized—resulting in an impressed voltage or current on the circuit being analyzed.

Human action. The motion(s), decision(s), or thinking of one or more persons required to complete a mission defined by the context of an accident scenario.

Human error. The failure of a human action modeled in a PRA that results in the failure of a plant function, system, or component. Excludes malevolent behavior.

Human error probability (HEP). A measure of the likelihood that plant personnel will fail to initiate the correct, required, or specific action or response in a given situation or by commission perform the wrong action.

Human failure event (HFE). A basic event in the fire PRA plant response model that represents a failure or unavailability of a piece of equipment, system, or function that is caused by human inaction or inappropriate action.

Human reliability analysis (HRA). A structured approach used to identify potential human failure events and to systematically estimate the probability of those errors using data, models, or expert judgment.

Ignition frequency. Frequency of fire occurrence generally expressed as fire ignitions per reactor-year.

Ignition source. Piece of equipment or activity that causes fire (per RG 1.189).

Initiating event. Any event—either internal or external to the plant—that perturbs the steady-state operation of the plant, if operating, thereby initiating an abnormal event such as transient or loss-of-coolant accident (LOCA) within the plant. *Initiating events* trigger sequences of events that challenge plant control and safety systems whose failure could potentially lead to core damage or large early release.

Internal event. An event originating within a nuclear power plant that, in combination with safety system failures and/or operator errors, can affect the operability of plant systems and may lead to core damage or large early release. By convention, loss of offsite power not caused by another external event is considered an *internal event*.

Internal events PRA model. The logic model (typically in terms of event trees and fault trees) depicting the combinations of internal initiating events (compared to external events such as tornadoes and seismic events), component failures (of causes internal to the components themselves), and human failure events that lead to core damage or large early release of other adverse events considered in a PRA.

Intervening combustibles. Materials that burn but are not ignition sources. These combustibles contribute to the propagation of the fire from the ignition source to the target and are usually located between the ignition source and the target.

Key safety functions. The minimum set of safety functions that must be maintained to prevent core damage and large early release. These include reactivity control, reactor pressure control, reactor coolant inventory control, decay heat removal, and containment integrity in appropriate combinations to prevent core damage and large early release.

Large early release frequency (LERF). Expected number of large early releases per unit of time.

LERF analysis. Evaluation of containment response to severe accident challenges and quantification of the mechanisms, amounts, and probabilities of subsequent radioactive material releases from the containment.

Level 1 analysis. Identification and quantification of the sequences of events leading to the onset of core damage.

Manual trip. A reactor trip initiated by the operators in response to an off-normal condition and in the absence of an automatic trip.

May. Used to state an option to be implemented at the user's discretion in the PRA Standard.

Mistake. A human cognitive error typically stemming from failure of diagnosis, decision making, or planning.

Modeling uncertainty. Imprecision in the analyst's knowledge or available information about how well the analyst's model represents the actual state of that being modeled in the PRA.

Multi-compartment fire scenario. A fire scenario involving targets in a room or fire compartment other than, or in addition to, the one in which the fire originated.

Multiple spurious operations. Concurrent spurious operations of two or more equipment items.

Open circuit. A loss of electrical continuity in an electrical circuit, either intentional or unintentional. As applied to wire and cable, open circuit faults may result, for example, from a loss of conductor continuity or from the triggering of circuit protection devices.

Operator. One of the shift operating personnel, or generally, any of a plant's personnel responsible for performing a desired action.

Operator manual action (OMA). Terminology used under pre-transition (Appendix R) licensing basis for an action performed by operators to manipulate components and equipment from outside the main control room to achieve and maintain post-fire hot shutdown, not including repairs.

Performance shaping factor (PSF). A factor that influences human error probabilities as considered in a PRA's human reliability analysis. It includes such items as level of training, quality/availability of procedural guidance, and time available to perform an action. In the context of a fire PRA, factors may include the influences of environmental factors such as visibility, toxic fumes, and smoke.

Plant. A general term used to refer to a nuclear power facility; for example, *plant* could be used to refer to a single unit or multi-unit site.

Point estimate. Estimate of a parameter in the form of a single number.

Primary control station (PCS). According to RG 1.205 Section C.2.4,[18] there are two cases in which operator actions taken outside the main control room may be considered as taking place at a *primary control station*. These two cases involve dedicated shutdown or alternate shutdown controls, which have been reviewed and approved by the NRC. In either case, the location or locations become primary when command and control is shifted from the main control room to these other locations. For these two cases, the operator actions are not considered recovery actions, even if they are necessary to achieve the nuclear safety performance criteria.

For the alternate shutdown case, such controls may be considered the *primary control station*—if, once enabled, the systems and equipment controlled from the panel are independent and electrically separated from the fire area and if the following additional criteria are met:

1. The location should be considered the primary command and control center when the main control room can no longer be used. The control room team will evacuate to this location and use its alternate shutdown controls to safely shut down the plant.
2. The location should have the requisite system and component controls, plant parameter indications, and communications so that the operator can adequately and safely monitor and control the plant using the alternate shutdown equipment.

More than one component should be controlled from this location. A local control station provided to allow an individual component, such as the local handwheel on a motor-operated valve, to be locally controlled does not meet this definition.

Probabilistic risk assessment (PRA). A qualitative and quantitative assessment of the risk associated with plant operation and maintenance that is measured in terms of frequency of occurrence of risk metrics, such as core damage or a radioactive material release, and its effects on the health of the public (also referred to as a *probabilistic safety assessment [PSA]*).

Probability of non-suppression. Probability of failing to suppress a fire before target damage occurs.

Raceway. An enclosed channel of metal or nonmetallic materials designed expressly for holding wires, cables, or bus bars, with additional functions as permitted by code. Raceways include rigid metal conduit, rigid nonmetallic conduit, intermediate metal conduit, liquid-tight flexible conduit, flexible metallic tubing, flexible metal conduit, electrical nonmetallic tubing, electrical metallic tubing, underfloor raceways, cellular concrete floor raceways, cellular metal floor raceways, surface raceways, wireways, and busways (per RG 1.189).

Reactor-year. A calendar year in the operating life of one reactor, regardless of power level.

Recovery action. A human action performed to regain equipment or system operability from a specific failure or human error to mitigate or reduce the consequences of the failure.

Response. The reaction to a cue or symptom of an event using procedures to control a function or system.

Response models. Represent post-initiator operator actions, following a cue or symptom of an event, to satisfy the procedural requirements for control of a function or system.

[18] The reference citation for RG 1.205 is given in Section 1 of this report.

Risk. Probability and consequences of an event as expressed by the *risk triplet*, that is, the answer to the following three questions: 1) What can go wrong? 2) How likely is it? and 3) What are the consequences if it occurs?.

Risk-relevant damage targets. Any equipment item or cable whose operation is credited in the fire PRA plant response model or whose operation may be required to support a credited post-fire operator action.

Risk-significant equipment. Equipment associated with a *significant basic event* as defined by the PRA Standard.

Safe shutdown (SSD) systems and equipment. Structures, systems, cables (power, instrumentation, and control), equipment, and components within the framework of Appendix R of 10 CFR Part 50 identified to achieve and maintain sub-critical reactivity conditions in the reactor, maintain reactor coolant inventory, and maintain safe and stable shutdown conditions following a fire-initiated event.

Safety function. Function that must be performed to control the sources of energy in the plant and radiation hazards.

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.

Secondary combustible. Combustible or flammable materials that are not part of the fire ignition source that may be ignited if fire is spread beyond the fire ignition source.

Sensitivity analysis. An analysis performed to investigate the sensitivity of the variability in model structure or data values on the products of the analysis (e.g., CDF). Although often done by changing the model or data value one at a time and determining the change in the analysis products, this analysis may be done by changing groups of variables in a logical manner.

Severity factor. The probability that fire ignition would include certain specific conditions that influence its rate of growth, level of energy emanated, and duration (time to self-extinguishment) to levels at which target damage is generated.

Shall. Used to state a mandatory requirement in the PRA Standard.

Should. Used to state a recommendation in the PRA Standard.

Skill-of-the-craft actions. Actions that one can assume that trained staff would be able to readily perform without written procedures (e.g., simple tasks such as turning a switch or opening a manual valve as opposed to a series of sequential actions or set of actions that need to be coordinated).

Smoke layer. Refers to the volume under the ceiling of a fire enclosure where smoke accumulates and high gas temperatures are observed. It is the upper zone in a two-zone model formulation.

Spurious operation. A circuit fault mode in which an operational mode of the circuit is initiated (in full or in part) because of failure(s) in one or more components (including cables) of the circuit.

Support system. A system that provides a support function (e.g., electric power, control power, or cooling) for one or more other systems.

Surrogate event. A PRA basic event used to simulate the impact of a fire-induced initiating event, including the resulting plant initiating event and/or component failures.

Target. May refer to a fire damage target and/or to an ignition target. A *fire damage target* is any item whose function can be adversely affected by the modeled fire. Typically, a *fire damage target* is a cable or equipment item that belongs to the fire PRA cable or equipment list and that is included in event trees and fault trees for fire risk estimation. An *ignition target* would be any flammable or combustible material to which fire might spread (per NUREG/CR-6850/EPRI 1011989).

Timeline and timing terms. Developing the timing information following the timeline shown in Figure A-1 is useful in that it applies to all quantification methods, as described in Section 4.6.2.

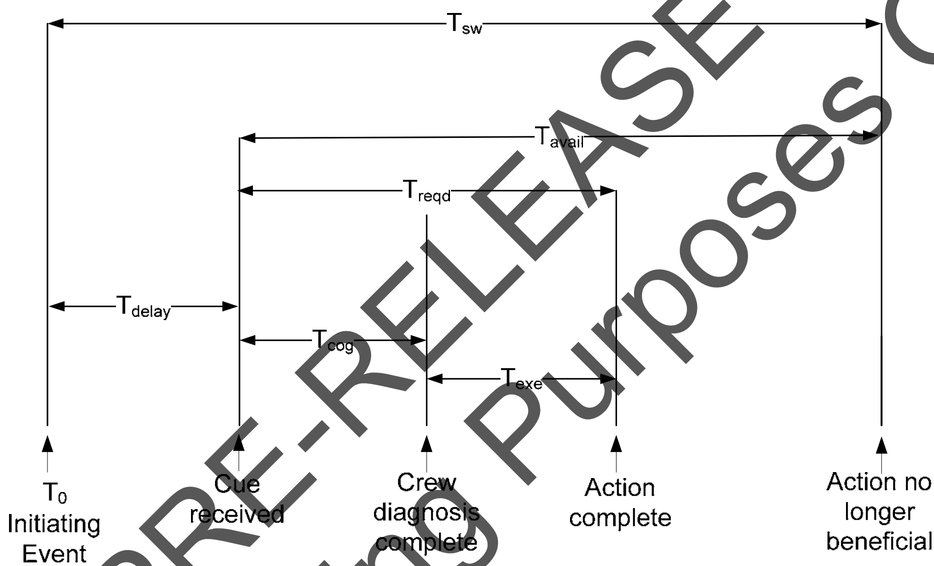


Figure A-1
Timeline illustration diagram

The terms associated with each timing element are defined mathematically next and then further described in the subsequent text.

T_0 = start time = start of the event

T_{delay} = time delay = duration of time it takes for an operator to acknowledge the cue

T_{sw} = system time window

T_{avail} = time available = time available for action = (T_{sw} - T_{delay})

T_{cog} = cognition time consisting of detection, diagnosis, and decision making

T_{exe} = execution time including travel, collection of tools, donning personnel protection equipment (PPE), and manipulation of components

T_{reqd} = time required = response time to accomplish the action = (T_{cog} + T_{exe})

Start time. In Figures 4-1 and A-1, T_0 is modeled as the start of the event. For fire HRA, T_0 can be either reactor trip (which is commonly the starting point for internal, non-fire PRA) or the start of the fire. The fire PRA typically assumes that reactor trip and the start of the fire occur at the same time unless scenario-specific factors show a significant difference.

System time window. T_{sw} is defined as the *system time window* and is the time from the start of the event until the action is no longer beneficial (typically when irreversible damage occurs, such as core damage or component damage). T_{sw} is typically derived from thermal hydraulic data and, for HRA quantification, is considered to be a static input. The *system time window* represents the maximum amount of time available for the action.

Delay time. T_{delay} represents the time from the start (typically the initiating event) until the time at which the operators acknowledge the cue. This is a function of the fire damage and the plant response, which includes taking into account any procedure delays or delays in responding to the cue. If the cue, for example, is a step in the fire procedure, T_{delay} would be the time it takes the operators to reach the step in the fire procedure. If the cue is an alarm that annunciates when a low tank level is reached, T_{delay} would be the time it takes to drain the tank until the alarm annunciates and the operator acknowledges the alarm. If the implementation of the appropriate procedures is delayed because the fire caused the control room crew to be in, or to consider, multiple procedures—such as the emergency operating procedures and the fire procedure(s)—the guidance is to systematically increase the *delay time* when updating existing internal events HFEs for use in the fire PRA. Similarly, if a particular fire area or fire scenario causes spurious alarms, indications, or actuation of components, the guidance is to systematically extend the *delay time* when updating existing internal events HFEs for use in the fire PRA. The *delay time* following fire initiating events is a source of modeling uncertainty in the current state of the art in fire PRA.

Cognition (recognition) time. T_{cog} is defined as the nominal time for cognition and includes detection, diagnosis, and decision making. T_{cog} is best obtained by simulator observations. For fire response actions, the diagnosis will typically be made in the control room and the execution local; therefore, it will still be possible to observe the *cognition time* from simulator observations. If there is a need to model local cognition, *cognition time* can be obtained by talk-throughs and/or walk-throughs (see Sections 4.3.4.1, 4.11.1, and 4.11.2).

Execution time. T_{exe} is the nominal time required for execution of the action. *Execution time* is defined as the time it takes for the operators to execute the action after successful diagnosis. The *execution time* includes the transit time to the local components, the time to collect tools and don PPE, and the time to manipulate the local components. The transit (travel) time could be significantly impacted by the fire location. Useful inputs to develop T_{exe} can be obtained from job performance measures (JPMs) or walk-throughs or talk-throughs with the operators (guidance provided in Sections 4.11.1 and 4.11.2). For control room actions, the guidance is to use the same T_{exe} from the internal events development (often called the *manipulation time* because typically there is no need for tools or PPE) for the fire event, unless the fire has impacted the control room (i.e., no smoke or hazards are present that would make manipulation more difficult). It is rare that the HRA analyst has the opportunity to collect enough data points for the same HFE to allow a distribution of times to be developed and the uncertainty to be formally calculated. More often, the availability of operations staff is limited, and there may be few opportunities to review the same HFE

timing with different individuals. It therefore becomes important for the analyst to recognize the potential for uncertainty in the time estimates and to be vigilant for cases in which a small change in the time estimation could render a feasible operator action infeasible or significantly impact the resulting HEP.

Time margin. *Time margin* is defined as the ratio of time available for the recovery action to the time required to perform the action (T_{cog}+T_{exe}) and is calculated as follows:

$$\text{Time Marin (TM)} = \frac{T_{avail} - T_{reqd}}{T_{reqd}} \times 100\% \qquad \textbf{Equation A-1}$$

$$\text{Time Marin (TM)} = \frac{\left[\left((T)_{sw} - T_{delay}\right) - \left(T_{cog} + T_{exe}\right)\right]}{\left(T_{cog} + T_{exe}\right)} \times 100\% \qquad \textbf{Equation A-2}$$

Transient combustibles. These combustible materials are temporarily stored in a location that is usually associated with (but not limited to) maintenance or modification activities. Examples of transient combustibles are combustible and flammable liquids, wood and plastic products, waste, scrap, rags, or any other combustibles resulting from the work activity.

Uncertainty. A 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. An uncertainty analysis includes developing a quantitative measure to the extent practical.

Verify. To determine that a particular action has been performed in accordance with the requirements of the PRA Standard, either by witnessing the action or by reviewing records.

Walkdown. Inspection of local areas in a nuclear power plant in which structures, systems, equipment, and cables are physically located in order to ensure the accuracy of procedures and drawings, equipment location, operating status, and environmental effects or system interaction effects on the equipment that could occur during accident conditions.

APPENDIX B
DETAILED QUANTIFICATION OF FIRE HUMAN FAILURE EVENTS USING THE EPRI FIRE HRA METHODOLOGY

B.1 Objective

This appendix presents a detailed methodology for the quantification of fire human error probabilities (HEPs) using the human reliability analysis (HRA) approach recommended by EPRI, specifically to use one or more of the following methods: human cognitive reliability/operator reliability experiment (HCR/ORE) [1] and/or cause-based decision tree method (CBDTM) [2] for cognition, and the technique for human error rate prediction (THERP) [3] for execution. The EPRI HRA methodology is based on EPRI's SHARP and SHARP1 HRA framework [4]. The approach in this appendix is to step HRA analysts through the HRA tasks needed to develop, quantify, and document HFEs.

The EPRI HRA approach and methodology embodies several of the HRA quantification methods currently used in the U.S. industry. These methods are primarily applied to Level 1 internal events probabilistic risk analysis (PRA) and large early release frequency (LERF) HRA. The methods are mostly task-based and decompose operator errors into two categories: cognitive failures (detection, diagnosis, and decision making) and execution failures (manipulation or implementation). These HRA methods provide sufficient resolution to meet the needs of the internal events PRA model. One advantage of using existing methods for fire HRA is that they evaluate fundamental aspects and factors affecting human performance—therefore, applying these methods to fire scenarios should yield a good first-order approximation of operator failure and would further be consistent with the modeling for non-fire scenarios at many nuclear power plants.

Although the methods used for fire HRA modeling are the same as those used for Level 1 internal initiating events, the context and fire impact require the analyst to consider fire-specific factors as provided in the guidance of this appendix. Potential fire impacts are summarized in Section 2.5 and Section 4. This quantification approach follows HFE identification and definition (described in Section 3) and qualitative analysis (presented in Section 4).

B.2 Performance Shaping Factors Using EPRI Approach

NUREG/CR-6850 [5] suggests that the following performance shaping factors (PSFs) (from NUREG-1792 [6]) be considered in quantification but does not describe how to model these effects:

- Available staffing resources
- Applicability and suitability of training and experiences
- Suitability of relevant procedures
- Availability and clarity of instrumentation

- Time available
- Environment in which the act needs to be performed
- Accessibility and operability of equipment to be manipulated
- Need for special tools
- Communications
- Team and crew dynamics
- Special fitness needs

The ASME/ANS PRA Standard [7] requires that the PSFs listed in Table B-1 be considered for post-initiators. These PSFs include most of the PSFs suggested by NUREG/CR-6850, but “communications” and “team/crew dynamics” are not explicitly stated in the ASME/ANS PRA Standard. “Special fitness needs” from NUREG/CR-6850 can be considered under “Environment” (e.g., lighting, heat, radiation) under which the operator is working” in the ASME/ANS PRA Standard.

Table B-1
PRA Standard supporting requirements (SRs) and performance shaping factors

SR [7]	Performance Shaping Factors
HR-F2	Accident sequence–specific timing of cues, and time window for successful completion
	Accident sequence–specific procedural guidance
	The availability of cues and other indications for detection and evaluation errors
	The specific high-level tasks (e.g., train level) required to achieve the goal of the response
HR-G3	Quality (type [classroom or simulator] and frequency) of the operator training or experience
	Quality of the written procedures and administrative controls
	Degree of clarity of the cues/indications
	Human-machine interface
	Time available and time required to complete the response
	Complexity of the required response
	Environment (e.g., lighting, heat, and radiation) under which the operator is working
	Accessibility of the equipment requiring manipulation
	Necessity, adequacy, and availability of special tools, parts, clothing, and so on
HR-G7	The time required to complete all actions in relation to the time available to perform the actions
	Factors that could lead to dependence (e.g., common instrumentation, common procedures, and increased stress
	Availability of resources (e.g., personnel)

The general PSFs incorporated in the EPRI HRA methodology are shown in Table B-2. The EPRI HRA methodology was specifically designed to meet the requirements of the ASME/ANS PRA Standard; therefore, the PSFs in the EPRI HRA methodology reflect those of the ASME/ANS PRA Standard.

Table B-2
EPRI HRA methodology performance shaping factors

Category	Performance Shaping Factors
Cue(s)	Initial
	Subsequent
Procedures	Cognitive
	Execution
	Other
Complexity of response	Cognitive
	Execution
Training	Classroom
	Simulator
	JPM
Timing	Delay time (when the cue occurs with respect to origin)
	System time window (time to reach undesired outcome)
	Manipulation time (to perform required action)
	Median response time (to detect, diagnose, and decide)
Accessibility	Main control room
	Locally for manual actions
Environmental	Lighting
	Heat/humidity
	Radiation
	Atmosphere
Special requirements	Tools
	Parts
	Clothing
Stress	Plant response as expected
	Workload
	Environmental PSFs (above)
Dependency analysis	Shift change
	Common cognitive
	Timing between cues
	Time required to complete actions
	Available resources
	Stress
	Same or different locations

The PSFs considered in the CBDTM implemented in the EPRI HRA methodology are listed in Table B-3.

Table B-3
CBDTM performance shaping factors

Type	Designator	Decision Tree	Performance Shaping Factors
Failures in the operator-information interface	p_c a:	Data not available	• Indication available in control room. • Indication accurate. • Warning or alternative in procedure. • Training on indication.
	p_c b:	Data not attended to	• Low versus high workload. • Check versus monitor. • Front versus back panel. • Alarmed versus not alarmed.
	p_c c:	Data misread or miscommunicated	• Indicators easy to locate. • Good/bad indicator. • Formal communications.
	p_c d:	Information misleading	• All cues as stated. • Warning of differences. • Specific training. • General training.
Failures in the operator-procedure interface	p_c e:	Relevant step in procedure missed	• Single versus multiple procedures. • Graphically distinct. • Placekeeping aids.
	p_c f:	Misinterpret instruction	• Standard unambiguous wording. • All required information. • Training on step.
	p_c g:	Error in interpreting logic	• "NOT" statement. • "AND" or "OR" statement. • Both "AND" and "OR" statements. • Practiced scenario.
	p_c h:	Deliberate violation	• Belief in adequacy of instruction. • Adverse consequence if comply. • Reasonable alternatives. • Policy of "verbatim" compliance.

The PSFs from NUREG-1792 [6], the ASME/ANS PRA Standard [7], and the CBDTM/THERP [2, 3] as embodied in the EPRI HRA methodology are summarized in Table B-4.

Table B-4
Performance shaping factors mapping

NUREG-1792 [6]	ASME/ANS PRA Standard [7]	CBDTM/THERP [2, 3]
Time available and time required to complete the action, including the impact of concurrent and competing activities.	Accident sequence–specific timing of cues and time window for successful completion (SR HR-F2)	Timing delay time (when cue occurs with respect to origin)
		Timing system time window (time to reach undesired outcome)
	Time available and time required to complete the response (SR HR-G3)	Timing system time window (time to reach undesired outcome)
		Timing manipulation time (to perform required action)
		Timing: median response time (to detect, diagnose, and decide)
		Timing: time available for recovery
Availability and clarity of instrumentation (cues to take actions as well as to confirm expected plant response).	The availability of cues and other indications for detection and evaluation errors (SR HR-F2)	Cue(s): initial
		Cue(s): subsequent
Ergonomic quality of human-system interface (HSI).	Degree of clarity of the cues/indications (SR HR-G3) Human-machine interface (SR HR-G3)	Data not available: indication available in control room
		Data not available: indication accurate
		Data not attended to: check versus monitor
		Data not attended to: front versus back panel
		Data not attended to: alarmed versus not alarmed
		Data misread or miscommunicated: indicators easy to locate
		Data misread or miscommunicated: good/bad indicator
		Information misleading: all cues as stated

Table B-4
Performance shaping factors mapping (continued)

NUREG-1792 [6]	ASME/ANS PRA Standard [7]	CBDTM/THERP [2, 3]
Suitability of relevant procedures and administrative controls.	Accident sequence–specific procedural guidance (SR HR-F2)	Procedures: cognitive
		Procedures: execution
		Procedures: other
	Quality of the written procedures and administrative controls (SR HR-G3)	Data not available: warning or alternative in procedure
		Information misleading: warning of differences
		Relevant step in procedure missed: single versus multiple
		Relevant step in procedure missed: graphically distinct
		Relevant step in procedure missed: placekeeping aids
		Misinterpret instruction: standard unambiguous wording
		Misinterpret instruction: all required information
		Error in interpreting logic: "NOT" statement
		Error in interpreting logic: "AND" or "OR" statement
		Error in interpreting logic: both "AND" and "OR" statements
		Deliberate violation: belief in adequacy of instruction
		Deliberate violation: adverse consequence if comply
		Deliberate violation: reasonable alternatives
		Deliberate violation: policy of "verbatim" compliance
	The specific high-level tasks (e.g., train level) required to achieve the goal of the response (SR HR-F2)	THERP [3] execution steps with EOM and EOC for each step

Table B-4
Performance shaping factors mapping (continued)

NUREG-1792 [6]	ASME/ANS PRA Standard [7]	CBDTM/THERP [2,3]
Applicability and suitability of training and experience.	Quality (type [classroom or simulator] and frequency) of the operator training or experience (SR HR-G3)	Training classroom
		Training simulator
		Training JPM
		Data not available: training on indication
		Information misleading: specific training
		Information misleading: general training
		Misinterpret instruction: training on step
		Error in interpreting logic: practiced scenario
Complexity of required diagnosis and response. In addition to the usual aspects of complexity, special sequencing, organization, and coordination can also be contributors to complexity.	Complexity of the required response (SR HR-G3)	Complexity of response: cognitive
		Complexity of response: execution
	The specific high-level tasks (e.g., train level) required to achieve the goal of the response (SR HR-F2)	THERP [3] execution steps with EOM and EOC for each step
	Factors that could lead to dependence (e.g., common instrumentation, common procedures, and increased stress) (SR HR-G7)	Dependency analysis: timing between cues
		Dependency analysis: timing shift change
		Dependency analysis: common cognitive
		Dependency analysis: time required to complete actions
		Dependency analysis: stress
		Dependency analysis: same or different locations

Table B-4
Performance shaping factors mapping (continued)

NUREG-1792 [6]	ASME/ANS PRA Standard [7]	CBDTM/THERP [2,3]
Workload, time pressure, and stress.	All listed under SR-HR-F2 and SR-HR-G3	Stress: plant response as expected
		Stress: workload
		Stress: environmental PSFs
		Data not attended to: low versus high workload
Environment in which the action needs to be performed.	Environment (e.g., lighting, heat, and radiation) under which the operator is working (SR HR-G3)	Environmental: lighting
		Environmental: heat/humidity
		Environmental: radiation
		Environmental: atmosphere
Special fitness needs (for special situations expected to involve the use of heavy or awkward tools or equipment, carrying hoses, climbing, and so on).	The specific high-level tasks (e.g., train level) required to achieve the goal of the response (SR HR-F2)	THERP [3] execution steps with EOM and EOC for each step
		Special requirements: tools
		Special requirements: parts
		Special requirements: clothing
Accessibility and operability of equipment to be manipulated.	Accessibility of the equipment requiring manipulation (SR HR-G3)	Accessibility: main control room
		Accessibility: locally for manual actions
The need for special tools (keys, ladders, hoses, and clothing such as to enter a radiation area).	Necessity, adequacy, and availability of special tools, parts, clothing, and so on (SR HR-G3)	Special requirements: tools
		Special requirements: parts
		Special requirements: clothing

Table B-4
Performance shaping factors mapping (continued)

NUREG-1792 [6]	ASME/ANS PRA Standard [7]	CBDTM/THERP [2,3]
Available staffing and resources.	Availability of resources (e.g., personnel) (SR HR-G7)	Dependency analysis: available resources
	Sufficient manpower to perform the action (HR-SR-H2)	
Communications (strategy and coordination) as well as whether one can be easily heard.		Data misread or miscommunicated: formal communications
Team/crew dynamics and crew characteristics (degree of independence among individuals, operator attitudes/biases/rules, use of status checks, and approach for implementing procedures [e.g., aggressive **versus** slow and methodical].	Account for any dependency between the HFE for recovery and any other HFEs in the sequence, scenario, or cutset to which the recovery is applied (HR-SR-H3)	Recovery by self-review, extra crew, STA, or ERF
Consideration of “realistic” accident sequence diversions and deviations (e.g., extraneous alarms, failed instruments, outside discussions, and sequence evolution not exactly like the one trained on).		Data not available: indication available in control room
		Data not available: indication accurate
		Information misleading: all cues as stated

B.3 Post-Initiator HFE Analysis Framework Using the EPRI Approach

The EPRI approach for the quantification of post-initiator HFEs—regardless of the initiators (e.g., fire, internal events, or flood)—is to classify the HFE into two phases: 1) detection, diagnosis, and decision-making, and 2) action. There are three possible outcomes: 1) a success of both the cognition and execution phases (correct response), 2) a failure in the execution phase after successfully recognizing what actions must be taken, and 3) a failure to recognize what action must be taken due to a failure of detection, failure of diagnosis, or failure of decision-making. This representation is diagrammed in Figure B-1 for the purpose of quantification.

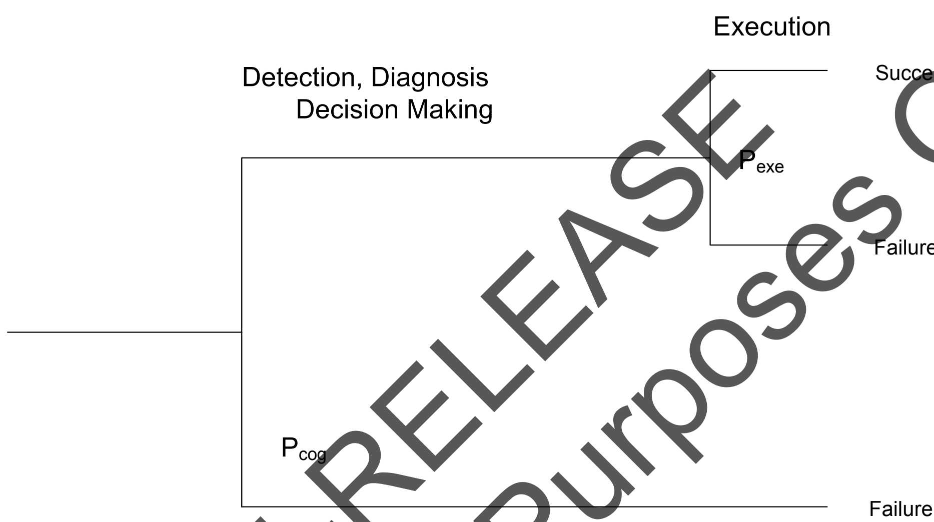


Figure B-1
Post-initiator general HFE analysis framework

In Figure B-1, P_{cog} is quantified using CBDTM [2] or HCR/ORE [1], and P_{exe} is quantified using THERP [3]. For P_{cog}, the total cognitive failure is calculated as either the sum or the maximum of the CBDTM and HCR/ORE values consistent with the approach taken in the internal events HRA.

For existing EOP actions, which were previously modeled in detail following the EPRI HRA methodology, the fire HFE analysis follows the same framework. For existing EOP actions that were not modeled using the EPRI HRA methodology, this is not necessarily true. The base case (existing EOP) HFE must first be quantified using the EPRI HRA methodology or other suitable methodologies that develop human error probabilities (HEPs); the base case analysis can then be modified to account for fire impacts. For fire response actions where there was not a pre-existing detailed HFE development, the EPRI HRA methodology would be used for quantification and the fire HRA will follow this framework.

Before quantifying an HFE, the analyst must have applied the criteria discussed in Section 4.3 for assessing the feasibility of the operator action(s) associated with that HFE. Although the feasibility assessment process begins at the identification and definition stage and is a key part of the initial qualitative analysis, new information may be available during the quantification process that would require the feasibility to be reassessed. Therefore, feasibility assessment is a continuous action step throughout the fire HRA.

Following the feasibility analysis for both fire HRA and internal events HRA, there are several types of HFEs that can be evaluated to 1.0 based on a simple qualitative analysis. For the scenario identified, if any one of the following is true, the HEP evaluates to 1.0. It is outside the scope of the EPRI method to quantify these types of actions for the following reasons:

- There is not enough time to complete the action. In EPRI terms, this means that the time available (T_{avail}) is less than the time required (T_{reqd}).
- There is not enough crew available to complete the action within the required time.
- There are no cues for diagnosis. The EPRI approach bases the quantification of cognition on the identification and interpretation of cues. If the fire fails all of the instrumentation required for diagnosis, there is no reason to expect that the operator will respond correctly.
- If the manipulations of a component take place in a location that is inaccessible, the action is not feasible.

B.4 Timing and Crew Response Structure

Developing the timeline is fundamental to understand the EPRI approach. The EPRI HRA approach follows the same timeline as outlined in Section 4.6.2. The timing analysis documents the source of the timing in accordance with ASME/ANS PRA Standard Requirements HR-G4 and HR-G5 [7] and is shown in Figure B-2.

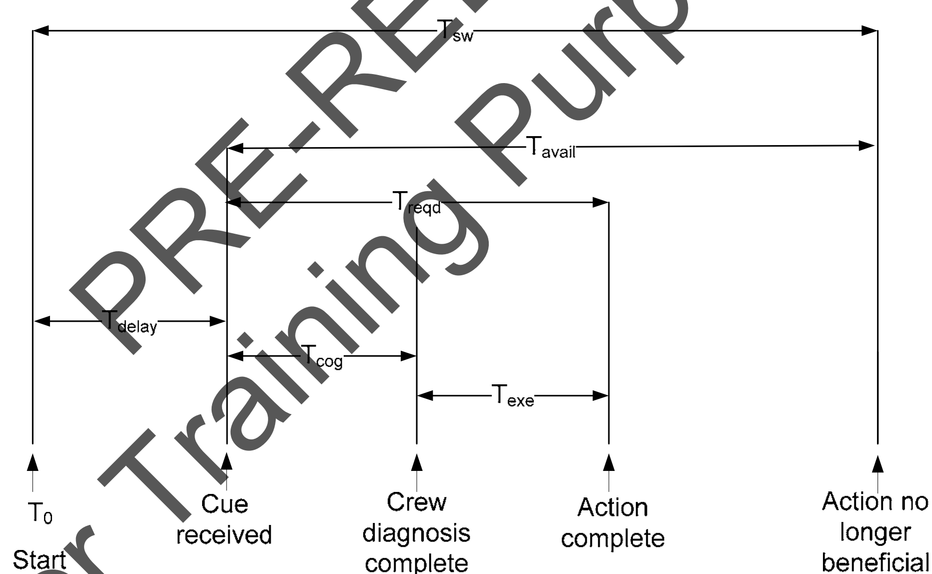


Figure B-2
Timing analysis framework

The terms associated with each timing element are defined mathematically next and then further described in Section 4.6.2.

T_0 = start time = start of the event

T_{delay} = time delay = duration of time it takes for an operator to acknowledge the cue

T_{sw} = system time window

T_{avail} = time available = time available for action = (T_{sw} - T_{delay})

T_{cog} = cognition time consisting of detection, diagnosis, and decision making

T_{exe} = T_m = execution time including travel, collection of tools, donning of PPE, and manipulation of components

T_{reqd} = time required = response time to accomplish the action = (T_{cog} + T_{exe})

For this appendix on the EPRI fire HRA quantification methods, the *cognition time* is typically taken as the same as the *median response time* used in the HCR/ORE method ($T_{cog} = T_{1/2}$); the terms are used interchangeably throughout the appendix. The guidance in Section 4.6.2 describes that T_{cog} should be a bounding estimate, especially when used in feasibility analyses. However, when used in the quantification of HCR/ORE, it is appropriate for T_{cog} to be a different time than $T_{1/2}$ (the median response time), as long as the data is available.

In the HCR/ORE method, the variance between crews (i.e., sigma) is an important factor in quantifying the HFE. The HCR/ORE studies identified the three types of actions, based on cue response structure and the timeline development, important to the variances between crews. The three cue response structures are presented in Figure B-3. The HCR/ORE correlation uses these classifications to determine *sigma*, which is a measure of crew-to-crew variability:

- **CP1** HFEs are simple proceduralized actions. **If** the cue is received, the operators will respond to it, for example, a procedure step that reads “Check AFW flow. If no flow, start AFW pump.”
- **CP2** HFEs are actions in which the operators receive an alert but must delay implementation until a specific plant parameter is reached. An example would be a situation in which the cues for feed and bleed are stated early in the procedure and the operators are directed to continue with procedure **until** the SG level reaches a specific point. When the SG level limits are reached, the operators perform feed and bleed. CP2 actions require that the operators be instructed to perform an action **when**—and not before—a plant limit is reached.
- **CP3** HFEs are actions in which the operators must diagnose and respond **before** a plant limit is reached. For a loss of all AFW, the procedures direct the operators to try to restore AFW until the cues for feed and bleed are met. In this case, the cue for restoring AFW would be the loss of all AFW, and the operators must complete this action before the cues for feed and bleed are reached.

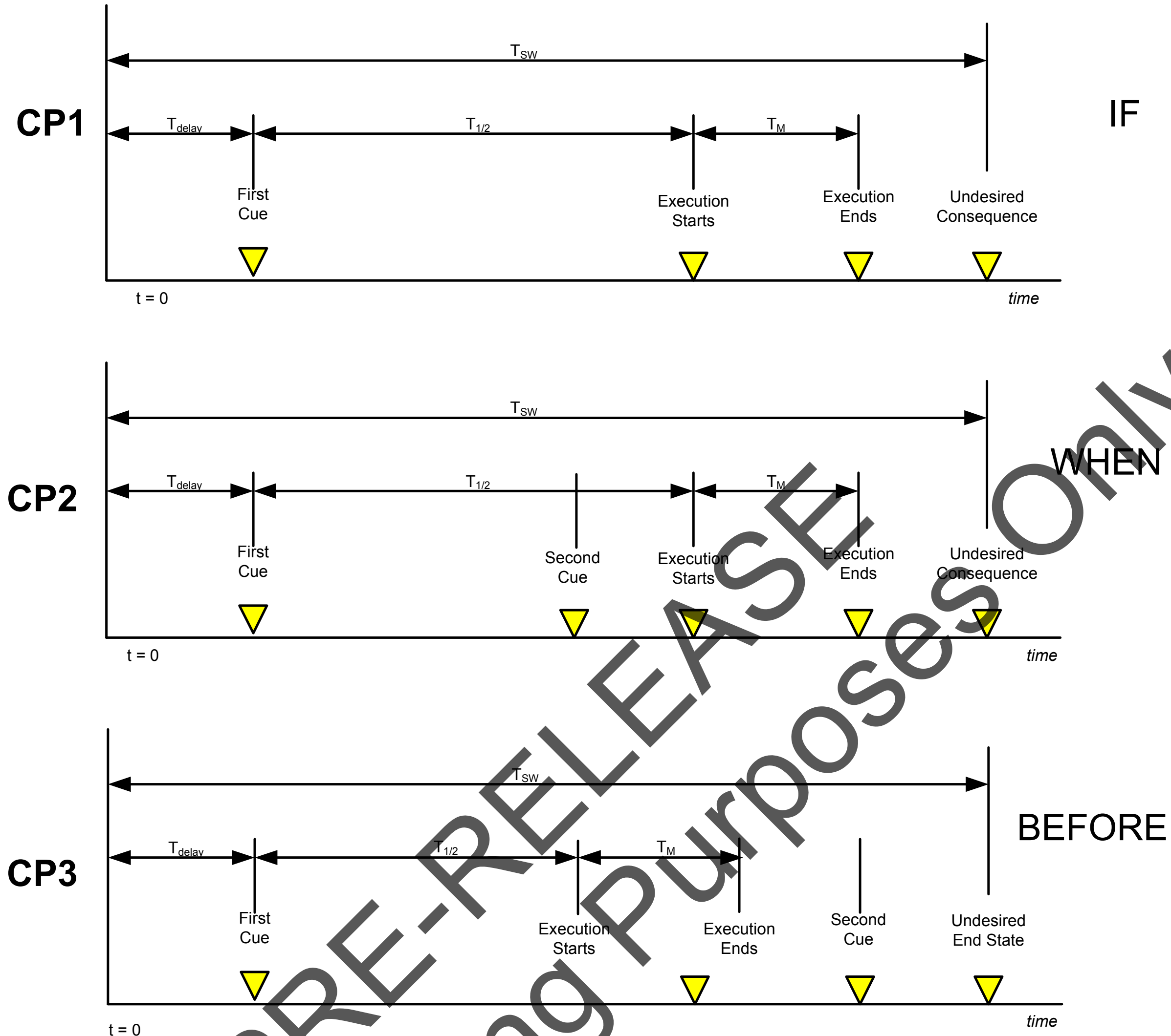


Figure B-3
Cue-response structure timelines for Type CP operator actions

B.5 Instrumentation Failure and Spurious Component Impact Following Fire

B.5.1 Instrumentation

For discussion purposes, there are three categories of potential fire impacts on instrumentation credited for cognition:

- No impact: all of the required instrumentation is available.
- Partial impact: a minimum set of the required instrumentation is available.
- Total impact: less than the minimum set of required instrumentation is available.

The following information is needed to evaluate the impact:

- Are the required indications available in the control room?
  - This is successful if all indications for the specific action are available or if a minimum set of information for the specific action is available.
  - This is unsuccessful if all indications for the specific action are failed. This is the case for total impact: no instrumentation is available, and the HEP evaluates to 1.0.
- Are the indications that are available accurate?
  - The indications are known to be accurate if the fire does not impact any of the instrumentation required for the specific action.
  - The indications are assumed to be inaccurate if there is a partial impact.
- If the normally displayed information is expected to be unreliable, is a warning or a note directing alternative information sources provided in the procedures?
  - The procedure lists alternative instrumentation to perform the specific task or provides a warning of potentially incorrect readings.
  - The procedure provides no alternative instrumentation or a warning. In this case, for existing EOP actions, there are no warnings in the EOPs for fire-related impact on the instrumentation.
- Has the crew received training in interpreting or obtaining the required information under conditions similar to those prevailing in this scenario?
  - The operating crew has received training in interpreting or obtaining the needed information under a fire situation. For cases in which there is partial impact (i.e., a minimum set of instrumentation remains available), the cognitive HEP evaluates to 5.0E-02 if no recoveries are applied.
  - The operating crew has not received training in interpreting or obtaining the needed information under a fire situation. If operators are not trained on performing the EOPs during fire scenarios, the cognitive HEP will evaluate to 0.5 for cases with partial impact on instrumentation if no recoveries are applied.

These impacts can be modeled directly in the EPRI HRA methodology using the CBDTM and modifying the branch selections for $p_c a$ and $p_c d$ and are discussed in detail in the following sections.

B.5.2 Fire-Induced Cable Failure(s) and Electrical Faults

Section 2.5 describes the range of fire-induced cable failure(s) and how these failures are reflected in the fire PRA models. Section 4.10 provides additional considerations for the treatment of the qualitative analysis associated with the operator response to fire-induced cable failures. One of the difficulties in the current fire HRA methods, including the EPRI HRA methods, is capturing the impact of instrument and equipment failures on the operator when a success path is available. Optimally, the operator recognizes—but is impervious to—the instrument and equipment failures and focuses directly on the train available for safe shutdown. More realistically, the operator may be distracted by these failures. The EPRI approach provides

a rough accounting for the distractions by the treatment of delay time in the timing analysis and by the selection of multiple procedures in the cognitive model. Additional guidance is provided in Section 4.10, such as to flag scenarios in which distractions may be more likely and to reflect the potential modeling uncertainty as discussed in Section 6.3.

B.6 Procedure Considerations Following Fire

Real-world events under complex situations have shown that operator response is improved by having procedures available. Operational experience also has shown that complex situations may slow the typical response to procedures or lead to the selection of the wrong procedure, especially for scenarios in which instrumentation is affected or training does not cover the specific situation. In addition, the current state of the art in fire procedures and fire training is improving as insights from the fire PRA models and/or the transition to National Fire Protection Association (NFPA) 805 occur. The EPRI quantification approach assumes that the operators follow procedures. Scenarios that may be challenging from a procedural perspective should be treated similarly to those described in Section B.5.2 and following the guidance provided in Section 4.10 (e.g., flag scenarios in which procedural distractions may be more likely and reflect the potential modeling uncertainty as discussed in Section 6.3).

B.7 Quantification Using the EPRI Approach

Using the EPRI HRA methodology, it is relatively easy to modify existing internal events HFEs to reflect fire impacts. Although the quantification of fire response actions follows the same approach as for existing actions, there is no previous analysis to build on—and the HFE must be developed as a new HFE within the fire contexts. Following detailed fire PRA development and operator interviews, the HFEs may be finalized by incorporating operator interview insights and/or other insights from the fire PRA model.

B.7.1 Method Selection

Similar to internal events HRA, both the CBDTM and the HCR/ORE are to be considered for fire HRA. Both methods address detection, diagnosis, and decision making—the HCR/ORE implicitly and the CBDTM explicitly. The CBDTM was developed to provide a lower limit on the probability because the HCR/ORE calculates very low probabilities for HFEs for which the time available is long relative to the time required. For fire HRA, instrument impacts and PSF impacts can be directly addressed using the CBDTM. The same questions that are asked for internal events HRA for quantification are asked for fire HRA. The HRA analyst's response (in many cases, the selection in the decision trees) can be very different between the fire and internal events case. Because the EPRI approach for quantification is symptom based, not initiator based, the same questions are still applicable for fire HRA.

B.7.2 EPRI HFE Approach and Documentation

The subsections in this appendix follow the format of the EPRI HRA methodology. The fields described are fields common to all methods used in the EPRI HRA methodology. The following sections apply to all HFEs, whether they are fire response HFEs or existing internal events HFEs.

B.7.2.1 HFE Approach

To begin quantification, a new HFE basic event ID is defined. It is good practice to set up a naming convention for HFEs that will allow for multiple variations of the same HFE.

For existing HFEs, the basic event record can be copied to a new record to allow for consistency and easy modification. Figures B-4 and B-5 show screen shots of the basic event data for a fire HFE. The *Related Human Interactions* field could list the variations of the basic event (if any). For existing EOP HFEs, the *Related Human Interactions* field could list the basic event from which the HFE was derived.

For fire response HFEs, a new basic event is created.

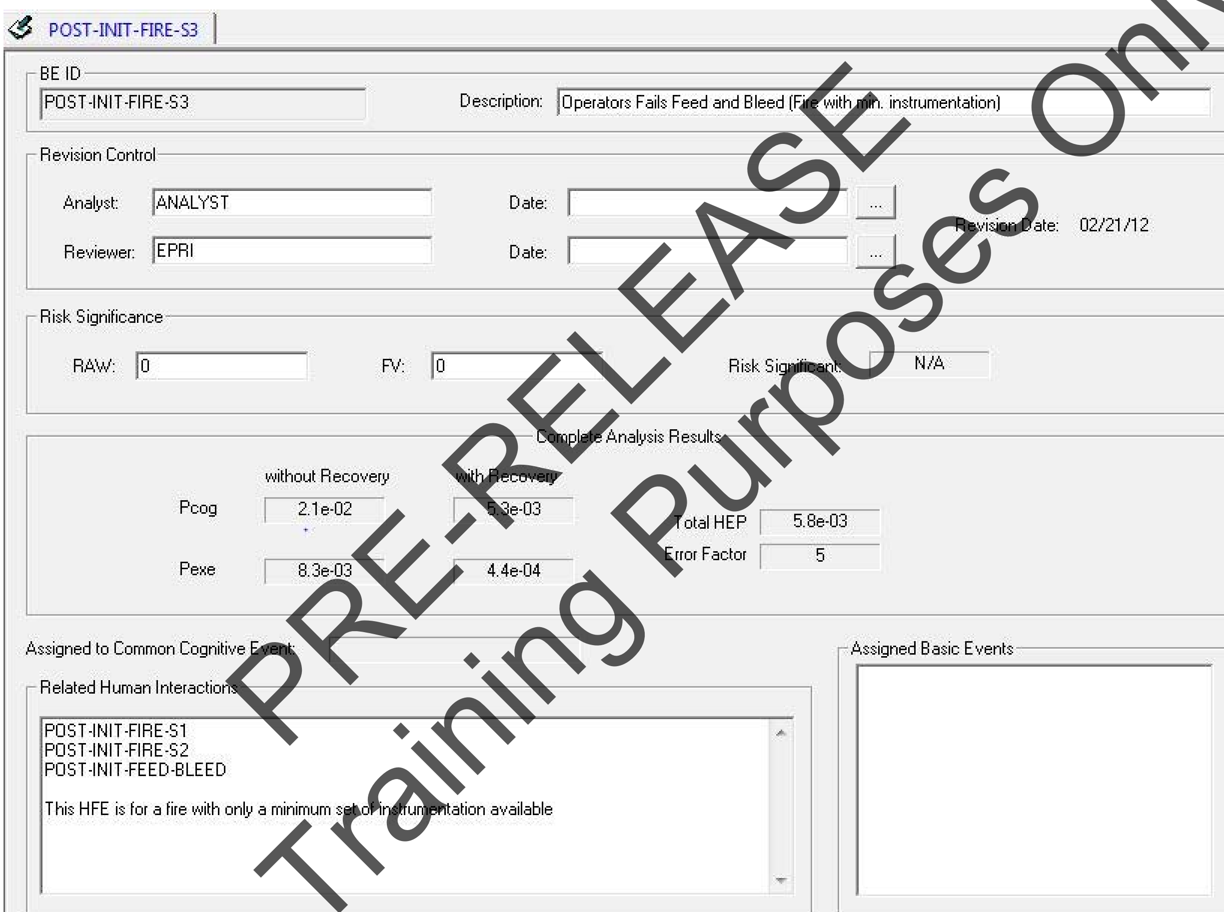


Figure B-4
EPRI HRA methodology basic event setup for fire HFE analysis

POST-INIT-FEED-BLEED	Post					... .. Operators fails feed and bleed (Base Case)
Annunciator Response/THERP		2.7e-04	4.4e-04	7.1e-04	10	
ASEP		3.6e-06	4.4e-04	4.4e-04	10	
CBDTM/HCR Combination (Sum)		3.3e-04	4.4e-04	7.6e-04	10	
CBDTM/THERP	X	3.3e-04	4.4e-04	7.6e-04	10	
HCR/ORE/THERP		4.1e-13	4.4e-04	4.4e-04	10	
Screening HEP		-	-	1.0e+00	1	
SPAR-H		1.0e-02	1.0e-03	1.1e-02	-	
POST-INIT-FIRE-S1	Post					... .. Operators Fails Feed and Bleed (Fire with all instrumentation available)
Annunciator Response/THERP		2.7e-04	4.4e-04	7.1e-04	10	
ASEP		3.6e-06	4.4e-04	4.4e-04	10	
CBDTM/HCR Combination (Sum)		5.3e-03	4.4e-04	5.8e-03	5	
CBDTM/THERP	X	5.3e-03	4.4e-04	5.8e-03	5	
HCR/ORE/THERP		4.1e-13	4.4e-04	4.4e-04	10	
Screening HEP		-	-	1.0e+00	1	
SPAR-H		1.0e-02	1.0e-03	1.1e-02	-	
POST-INIT-FIRE-S2	Post					... .. Operators Fails Feed and Bleed (Fire with all instrumentation failed)
Annunciator Response/THERP		2.7e-04	4.4e-04	7.1e-04	10	
ASEP		3.6e-06	4.4e-04	4.4e-04	10	
CBDTM/HCR Combination (Sum)		1.0e+00	4.4e-04	1.0e+00	1	
CBDTM/THERP	X	1.0e+00	4.4e-04	1.0e+00	1	
HCR/ORE/THERP		4.1e-13	4.4e-04	4.4e-04	10	
Screening HEP		-	-	1.0e+00	1	
SPAR-H		1.0e-02	1.0e-03	1.1e-02	-	
POST-INIT-FIRE-S3	Post					... .. Operators Fails Feed and Bleed (Fire with min. instrumentation)
Annunciator Response/THERP		2.7e-04	4.4e-04	7.1e-04	10	
ASEP		3.6e-06	4.4e-04	4.4e-04	10	
CBDTM/HCR Combination (Sum)		5.3e-03	4.4e-04	5.8e-03	5	
CBDTM/THERP	X	5.3e-03	4.4e-04	5.8e-03	5	
HCR/ORE/THERP		4.1e-13	4.4e-04	4.4e-04	10	
Screening HEP		-	-	1.0e+00	1	
SPAR-H		1.0e-02	1.0e-03	1.1e-02	-	

Figure B-5
EPRI HRA Calculator screen shot showing multiple variations of a base case HFE

B.7.2.2 Cues

Cues are addressed in the same way for both fire and internal events HFE analyses. For fire HRA, the identification of the cues needs to include the specific instrumentation required for diagnosis in order to determine the availability of the cues for specific fires. If the instrumentation is entered into the *Initial Cue* or *Recovery Cue* fields, a complete list of all instrumentation required for fire HRA can be generated; this list can easily be incorporated into the component selection task (Task 2) of NUREG/CR-6850 [5]. Figure B-6 shows how the identification of cues is documented in the EPRI HRA methodology.

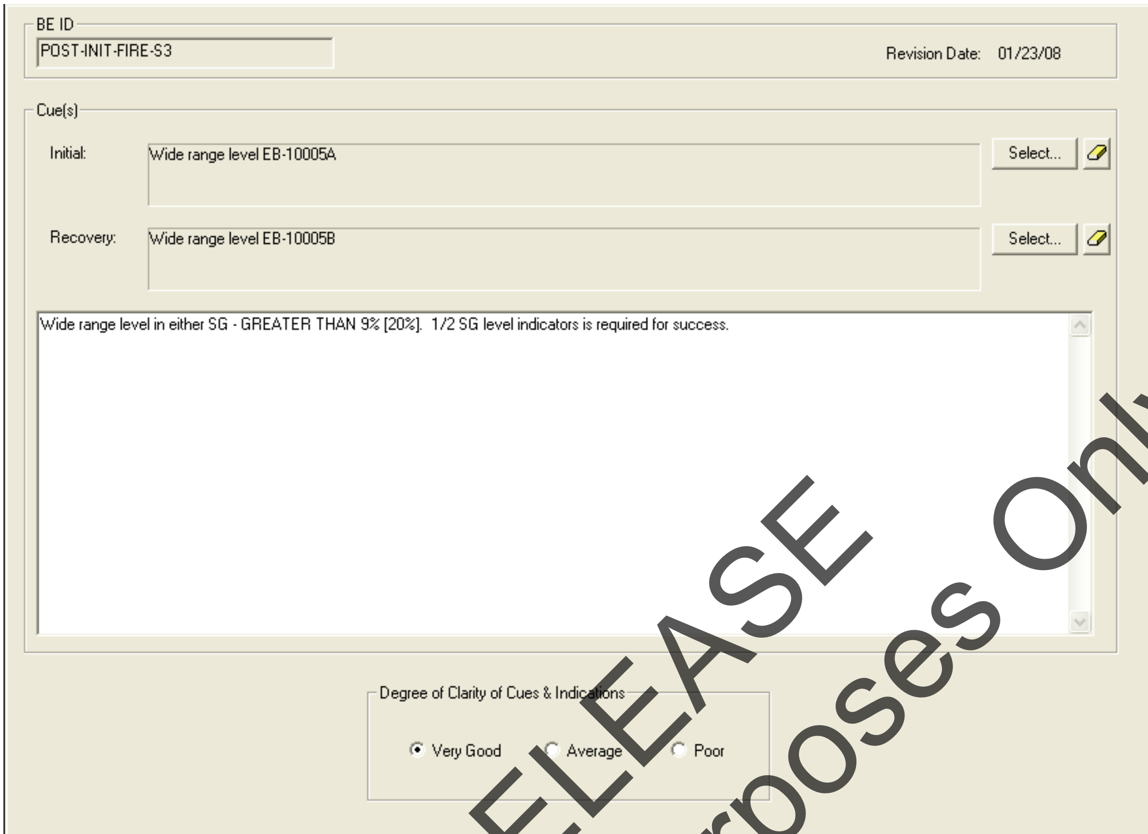


Figure B-6
EPRI HRA methodology identification of cues

B.7.2.3 Procedures

Procedures are addressed in the same way for fire and internal events HFEs. For fire HRA, there may be both an EOP and a fire procedure in use at the same time. The screen in Figure B-7 shows how the procedures are documented in the EPRI HRA methodology for a specific HFE. This window is provided for documentation purposes; the effects of the procedures on cognition are modeled in decision trees p_ca, p_cd, p_ce, p_cf, and p_ch. The procedures are also used to identify the critical task required for execution modeled using THERP.

In addition to the specific procedures for each HFE, the complete list of fire procedures reviewed during the fire procedures screening and review (ASME/ANS PRA Standard Requirement HR-E2) could be added to the procedures database for documentation. The procedures database is shown in Figure B-8.

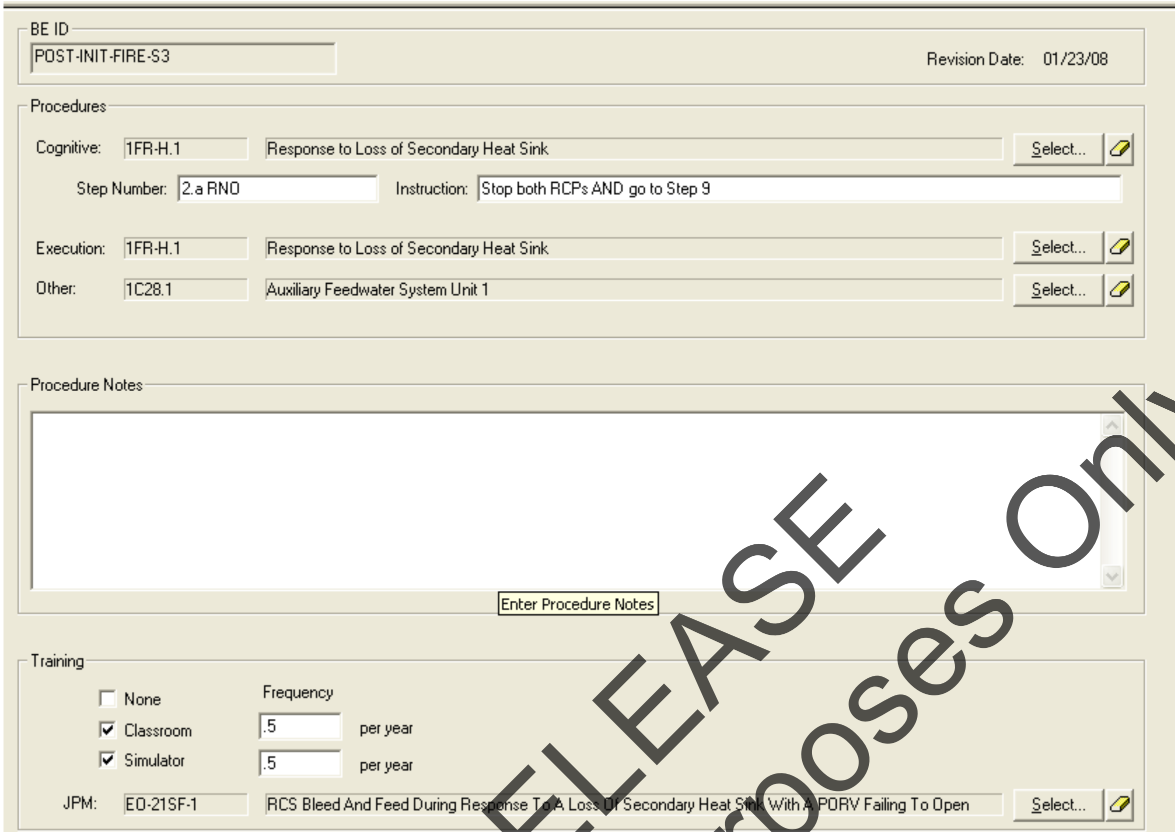
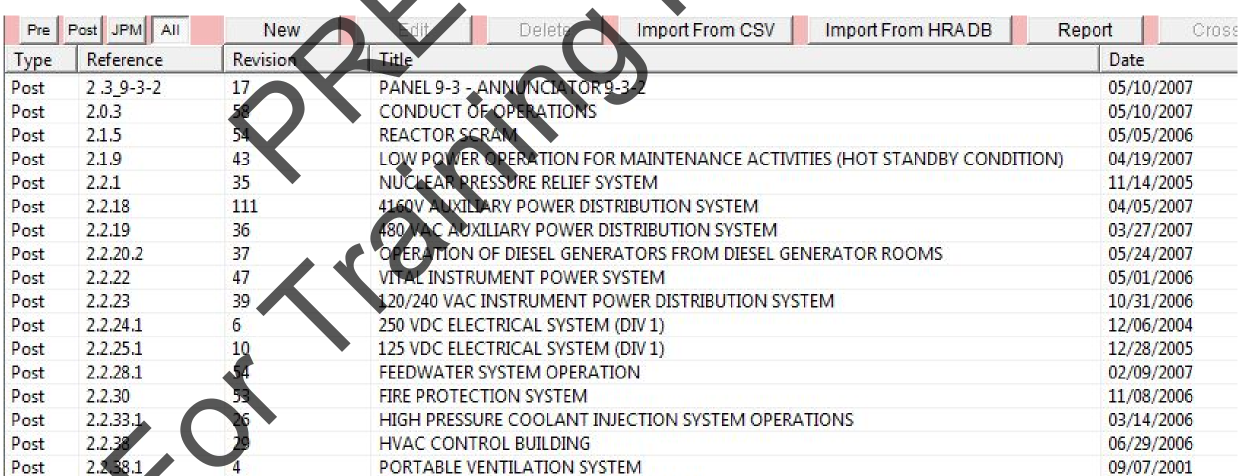


Figure B-7
EPRI HRA methodology documentation of procedures



Pre | Post | JPM | All | New | Edit | Delete | Import From CSV | Import From HRA DB | Report | Cross

Type	Reference	Revision	Title	Date
Post	2.3_9-3-2	17	PANEL 9-3 - ANNUNCIATOR 9-3-2	05/10/2007
Post	2.0.3	58	CONDUCT OF OPERATIONS	05/10/2007
Post	2.1.5	54	REACTOR SCRAM	05/05/2006
Post	2.1.9	43	LOW POWER OPERATION FOR MAINTENANCE ACTIVITIES (HOT STANDBY CONDITION)	04/19/2007
Post	2.2.1	35	NUCLEAR PRESSURE RELIEF SYSTEM	11/14/2005
Post	2.2.18	111	4160V AUXILIARY POWER DISTRIBUTION SYSTEM	04/05/2007
Post	2.2.19	36	480 VAC AUXILIARY POWER DISTRIBUTION SYSTEM	03/27/2007
Post	2.2.20.2	37	OPERATION OF DIESEL GENERATORS FROM DIESEL GENERATOR ROOMS	05/24/2007
Post	2.2.22	47	VITAL INSTRUMENT POWER SYSTEM	05/01/2006
Post	2.2.23	39	120/240 VAC INSTRUMENT POWER DISTRIBUTION SYSTEM	10/31/2006
Post	2.2.24.1	6	250 VDC ELECTRICAL SYSTEM (DIV 1)	12/06/2004
Post	2.2.25.1	10	125 VDC ELECTRICAL SYSTEM (DIV 1)	12/28/2005
Post	2.2.28.1	54	FEEDWATER SYSTEM OPERATION	02/09/2007
Post	2.2.30	53	FIRE PROTECTION SYSTEM	11/08/2006
Post	2.2.33.1	26	HIGH PRESSURE COOLANT INJECTION SYSTEM OPERATIONS	03/14/2006
Post	2.2.38	29	HVAC CONTROL BUILDING	06/29/2006
Post	2.2.38.1	4	PORTABLE VENTILATION SYSTEM	09/07/2001

Figure B-8
EPRI HRA methodology documentation of fire procedure review

B.7.2.4 Scenario Description

The HFE is defined and documented in accordance with the ASME/ANS PRA Standard High-Level Requirement HR-F1. The definition includes a qualitative analysis as discussed in Section 4 and can include specific descriptions of the following:

- Initial conditions
- Accident sequence
- Preceding operator errors and successes
- Operator success criteria
- Consequence of failure

Instrumentation impacts are also identified in the scenario description along with known equipment failed by the fire.

B.7.2.5 Operator Interviews

The insights gained from the operator interviews are documented in the *Operator Interview Insights* window (shown in Figure B-9) and include the following:

- Documentation of talk-throughs with plant operations and training personnel to confirm that the interpretation of the fire procedure is consistent with plant operation (ASME/ANS PRA Standard Requirement HR-E3).
- Documentation of talk-throughs with operators to confirm the response models for the scenarios modeled (ASME/ANS PRA Standard Requirement HR-E4).

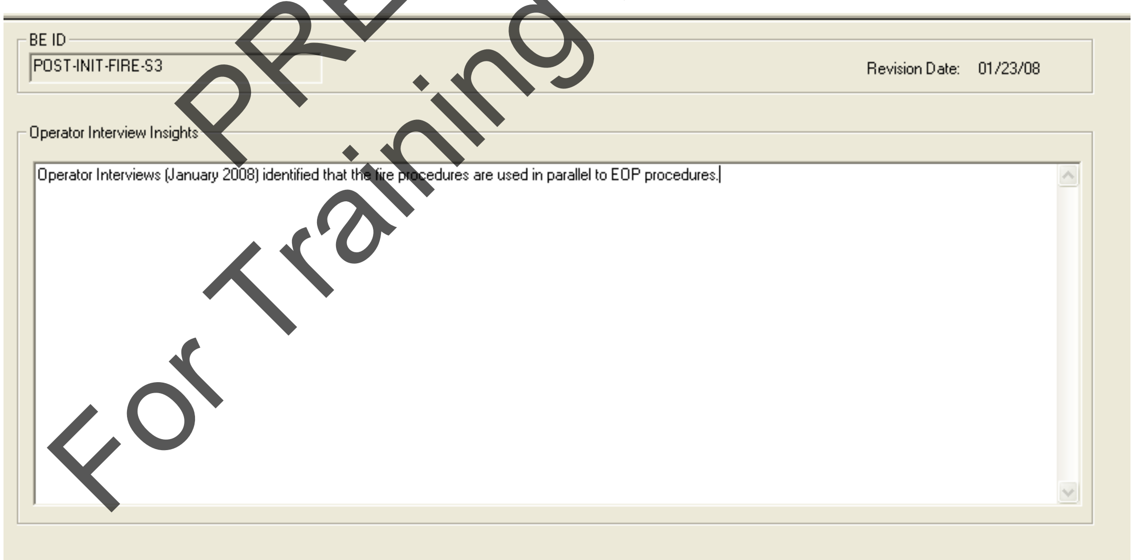


Figure B-9
EPRI HRA methodology operator interview insights window

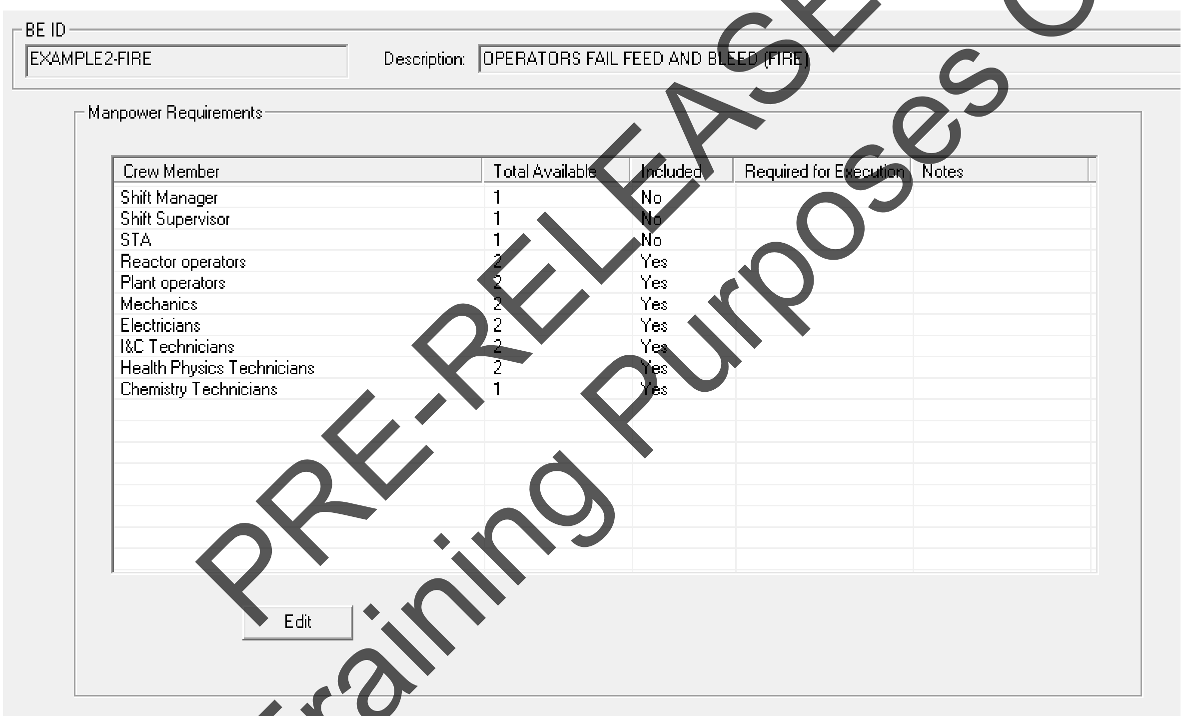
B.7.2.6 Manpower Requirements

As part of the analysis framework (see Figure B-1), the crew requirements should be identified and documented in the *Manpower Requirements* window (shown in Figure B-10). If there is not enough crew available to complete the actions, the HEP should be set to 1.0.

It should be noted that NUREG/CR-6850 Task 12 assumes the following:

> Even if one or more MCR persons are used to assist in ex-control room activities such as aiding the fire brigade, the minimum allowable number of plant operators remains available.

The manpower requirements for individual HFEs are used in the dependency analysis to verify that sufficient manpower would be available to perform all the actions implied by the HFEs in a cutset or sequence.



BE ID: EXAMPLE2-FIRE
Description: OPERATORS FAIL FEED AND BLEED (FIRE)

Manpower Requirements

Crew Member	Total Available	Included	Required for Execution	Notes
Shift Manager	1	No		
Shift Supervisor	1	No		
STA	1	No		
Reactor operators	2	Yes		
Plant operators	2	Yes		
Mechanics	2	Yes		
Electricians	2	Yes		
I&C Technicians	2	Yes		
Health Physics Technicians	2	Yes		
Chemistry Technicians	1	Yes		

Edit

Figure B-10
EPRI HRA methodology manpower requirements window

B.7.2.7 Time

Timing is documented in the EPRI HRA methodology as shown in Figure B-11.

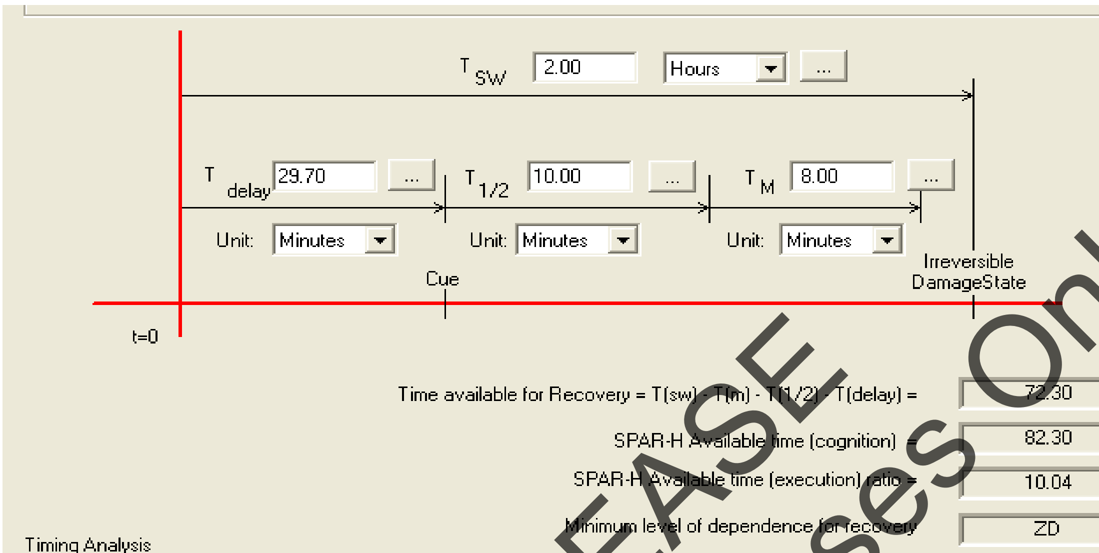


Figure B-11
EPRI HRA methodology timing window

The EPRI HRA method applies the following definitions for *time*:

- T_{SW} = system time window: this is usually the time from reactor trip (T=0) to an undesired end state
- T_{delay} = time from T=0 until cue is reached
- T_m = manipulation time
- $T_{1/2}$ = median response time

The *timing analysis* documents the source of the timing in accordance with ASME/ANS PRA Standard Requirements HR-G4 and HR-G5. For existing internal events HFEs, this field can document both the internal events timing and any adjustments made to account for the fire.

If the implementation of the EOPs is delayed because of the performance of the fire procedure(s), the delay time for all existing internal events HFEs is systematically increased by the average time it would take to perform the fire procedure(s), typically about 30 minutes. In this case, $T_{delay} = T_{delay\ base\ case} + 30$ min.

The manipulation time (T_m) should account for any travel time to reach the execution location. This travel time could be significantly impacted by the fire location. T_m can be obtained from a demonstration of feasibility, JPMs, or walk-throughs or talk-throughs with the operators. As an initial estimate for existing internal events HFEs, it is recommended that T_m be increased by at least 10 minutes for local actions. For control room actions, the same T_m used for internal events can be applied to the fire event, assuming that the fire has not impacted the control room (i.e., no smoke or hazards are present that would make manipulation more difficult).

If the *Time available for Recovery* is less than zero as in the example shown in Figure B-12, the HEP should evaluate to 1.0 because there is insufficient time to perform the action.

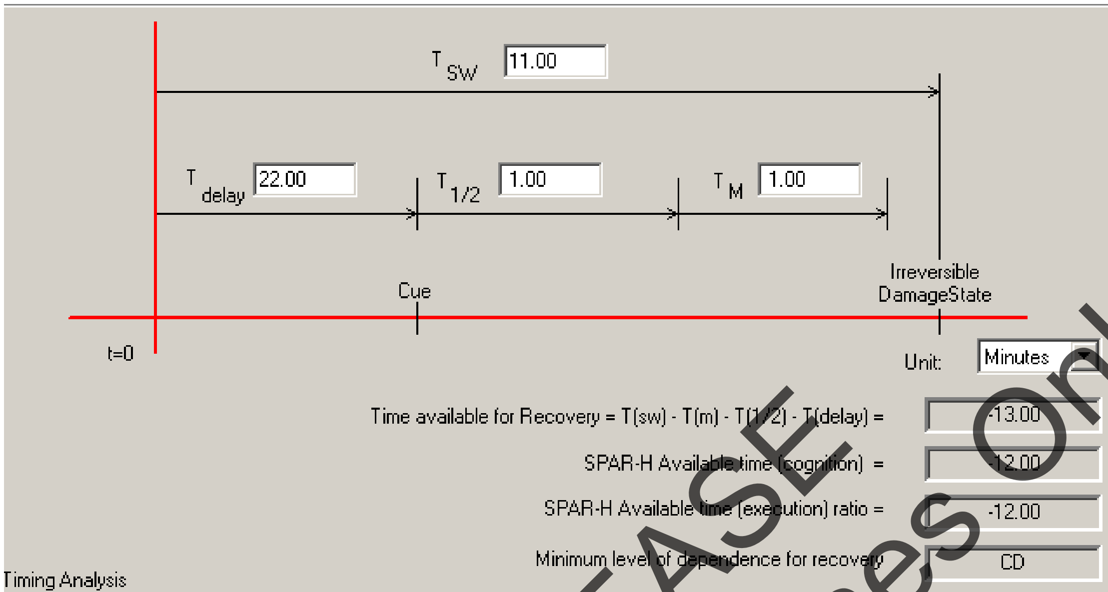


Figure B-12
Time window: time available for recovery is less than zero

B.7.3 Cognitive Modeling Using CBDTM

The CBDTM is used to assess cognitive HEPs for procedure-directed actions. It is applied to major decision steps such as transfers to another procedure or the decision to initiate a process. The CBDTM assesses HEPs by evaluating separate decision trees that evaluate each of the cognitive failure mechanisms shown in Table B-5. There are two high-level failure modes: failure of the operator-information interface and failure of the operator-procedure interface. Each high-level failure mode is composed of four failure mechanisms.

Table B-5
CBDTM failure mechanisms

High-Level Failure Mode	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

Guidance from EPRI TR-100259 on each of the CBDTM decision trees is provided in the following sections. Where applicable, additional guidance on how to model a fire scenario is also included.

B.7.3.1 Failure Mechanism a: Data Not Available

Guidance on Failure Mechanism *a* is shown in Figure B-13, Table B-6, and Figure B-14.

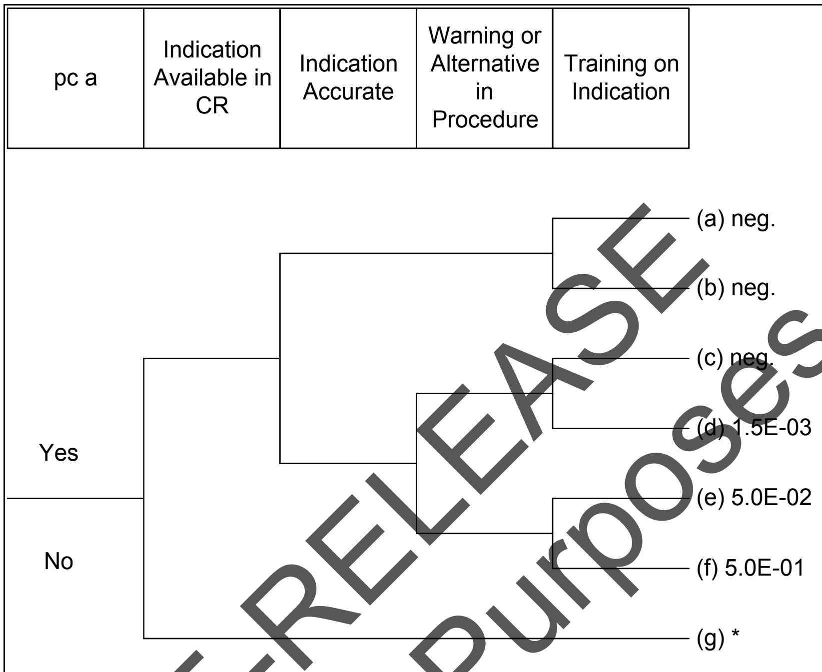


Figure B-13
Decision tree for $p_c a$: data not available

Note: The asterisk on branch (g) denotes the following: for situations where the crew must obtain information from ex-control room sources via a second-party report, the same analysis should be performed for the local plant operator, who may have different procedures (or none) and very different training than members from the control room crew. The time for the second party to obtain the information should be included in the delay time described in Section 4.6.2.

Table B-6
Guidance on decision nodes for p_ca: data not available

Decision Node	Guidance as Stated in EPRI TR-100259 [2]	Guidance Specific for Fire HRA
Indication available in CR	Is the required indication available in the control room?	The *Yes* branch is used when all indications for specific action are available or if a minimum set of information for the specific action is available. The *No* branch is used when all indications for the specific action are failed. This is the case for total impact: no instrumentation is available, and the HEP should evaluate to 1.0. If branch *g* is selected for this decision tree, the HRA methodology will display a warning that this HFE should be quantified as two separate actions: one for the control room and one for local actions. If there are no additional indicators (either in CR or locally) that can be credited for fire HRA, the HEP should be set to 1.0.
Indication accurate	Are the available indications accurate? If they are known to be inaccurate (e.g., due to degradation because of local extreme environment conditions or isolation of the instrumentation), select *No*.	The *Yes* branch is used when indications are known to be accurate and available during the fire. The *No* branch is used when the fire causes partial impact to the instrumentation and the indications are therefore assumed to be inaccurate.
Warning or alternative in procedure	If the normally displayed information is expected to be unreliable, is a warning or a note directing alternative information sources provided in the procedures?	The *Yes* branch is used when the procedure lists alternative instrumentation to perform the specific task or provides a warning of potentially incorrect readings during a fire. The *No* branch is used when the procedure provides no alternative instrumentation or a warning during a fire.
Training on indication	Has the crew received training in interpreting or obtaining the required information under conditions similar to those prevailing in this scenario?	The *Yes* branch is used when the operating crew has received training in interpreting or obtaining the needed information in a fire situation. The *No* branch is used when the operating crew has not received training in interpreting or obtaining the needed information under a fire situation.

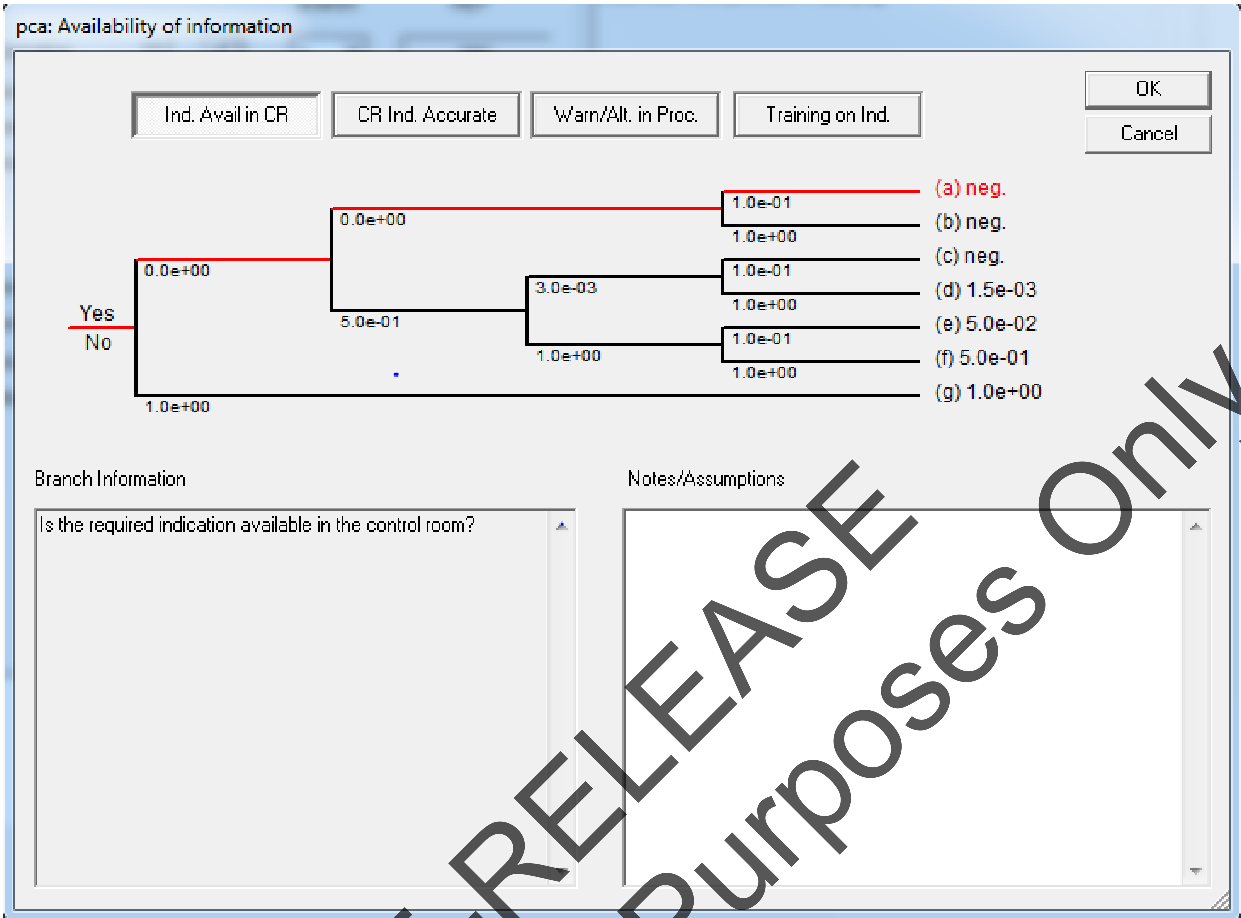


Figure B-14
EPRI HRA methodology p_{ca} branch selection to account for instrumentation partially impacted by fire with credit for general training

Branch (g) is shown as 1.0 in Figure B-14, but the software tool (EPRI HRA Calculator) provides an additional warning as described in Table B-6. If branch (g) is selected then the main control room crew must obtain information from ex-control room sources via a second-party report, the same analysis should be performed for the local plant operator, who may have different procedures (or none) and very different training than members from the control room crew. The time for the second party to obtain the information should be included in the delay time described in Section 4.6.2.

B.7.3.2 Failure Mechanism b: Data Not Attended to

Guidance on Failure Mechanism *b* is shown in Figure B-15, Table B-7, and Figure B-16.

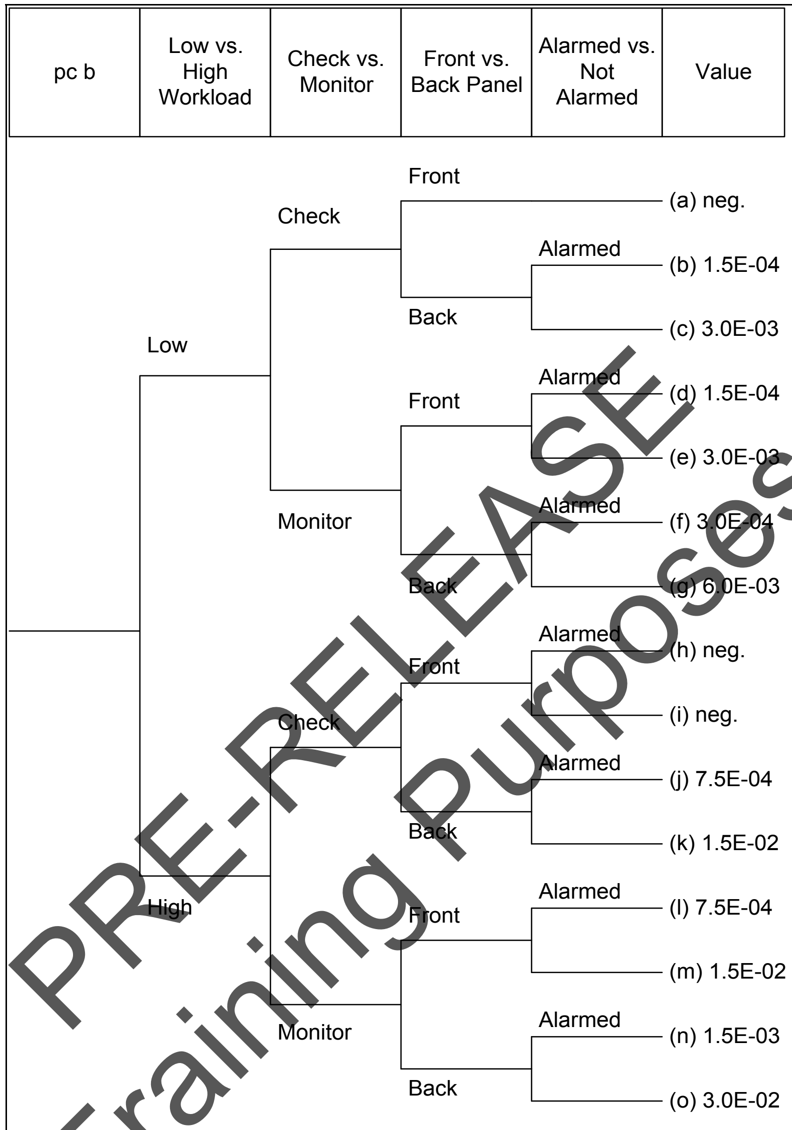


Figure B-15
Decision tree for p_cb: data not attended to

Table B-7
Guidance on decision nodes for p_cb: data not attended to

Decision Node	Guidance as Stated in EPRI TR-100259 [2]	Guidance Specific for Fire HRA
Low vs. High Workload	Do the cues critical to the human interaction (HI) occur at a time of high workload or distraction? Workload or distraction leading to a lapse of attention (omission of an intended check) is the basic failure mechanism for p_cb, and it interacts with the next two factors.	If the EOPs are implemented in parallel to the fire procedures, the workload is assumed high. However, if the action is time independent and the base case HFE (for existing EOP HFEs) is considered to have a low workload, the fire scenario can also be considered to have a low workload. In this case, it is assumed that the fire will be mitigated long before the action is required.
Check vs. Monitor	Is the operator required to perform a one-time check of a parameter, or monitor it until some specified value is reached or approached? The relatively high probabilities of failure for the monitor branches are included to indicate a failure to monitor frequently enough to catch the required trigger value prior to its being exceeded rather than complete failure to check the parameter occasionally.	No additional guidance for fire.
Front vs. Back Panel	Is the indicator to be checked displayed on the front panels of the main control area, or does the operator have to leave the main control area to read the indications? If so, the operator is more likely to be distracted or to simply decide that other matters are more pressing and not go to look at the cue immediately. Any postponement in attending to the cue increases the probability that it will be forgotten.	No additional guidance for fire.
Alarmed vs. Not Alarmed	Is the critical value of the cue signaled by an annunciator? If so, the operator is more likely to allow himself to check it, and the alarm acts as a preexisting recovery mechanism or added safety factor. For parameters that trigger action when a certain value is approached or exceeded (Type CP-2 and CP-3 HIs), these branches should be used only if the alarm setpoint is close to but anticipates the critical value of interest; where the alarm comes in long before the value of interest is reached, it will probably be silenced and thus not effective as a recovery mechanism.	If the critical value of the cue is signaled by an annunciator, it must also be unaffected during the fire in order to credit the alarm for recovery. If it is not known if the alarm is available during the fire, the alarm cannot be used as a recovery, and the lower branch is used.

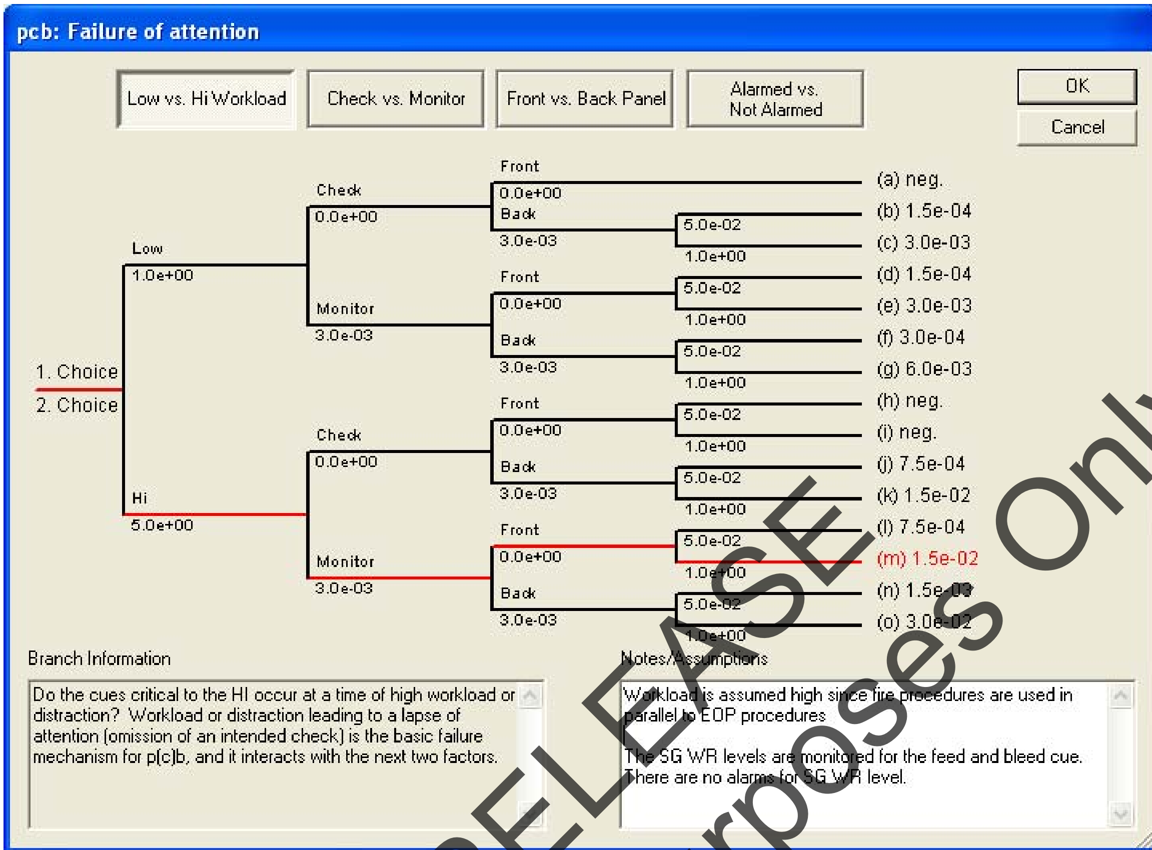


Figure B-16
EPRI HRA methodology p_cb branch selection to account for high workload from the use of fire procedures in parallel to EOPs

B.7.3.3 Failure Mechanism c: Data Misread or Miscommunicated

Guidance on Failure Mechanism *c* is shown in Figure B-17, Table B-8, and Figure B-18.

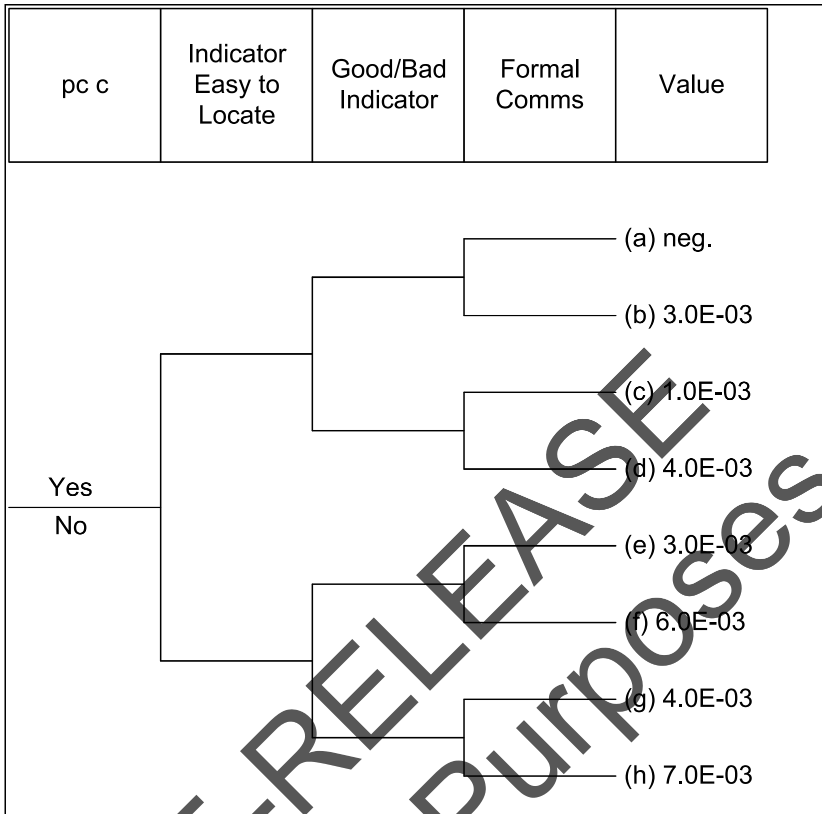


Figure B-17
Decision tree for p_cc: data misread or miscommunicated

Table B-8
Guidance on decision nodes for p_cC: data misread or miscommunicated

Decision Node	Guidance as Stated in EPRI TR-100259 [2]	Guidance Specific for Fire HRA
Indicator Easy to Locate	Are the layout, demarcation, and labeling of the control boards such that it is easy to locate the required indicator? The answer is *no* if there are obvious human factors deficiencies in these areas and the plausible candidates for confusion with the correct indicator are sufficiently similar that the values displayed would not cause the operator to recheck the identity of the indicator after reading it.	No additional guidance for fire.
Good/Bad Indicator	Does the required indicator have human engineering deficiencies that are conducive to errors in reading the display? If so, the lower branch is followed.	No additional guidance for fire.
Formal Communications	Is a formal or semi-formal communications protocol used in which the person transmitting a value always identifies the value with which the parameter is associated? (This limited formality is sufficient to allow the person receiving the information to detect any mistakes in understanding the request.)	If the fire requires the operators to wear SCBA, no credit is given for formal communication, and the *No* branch is used.

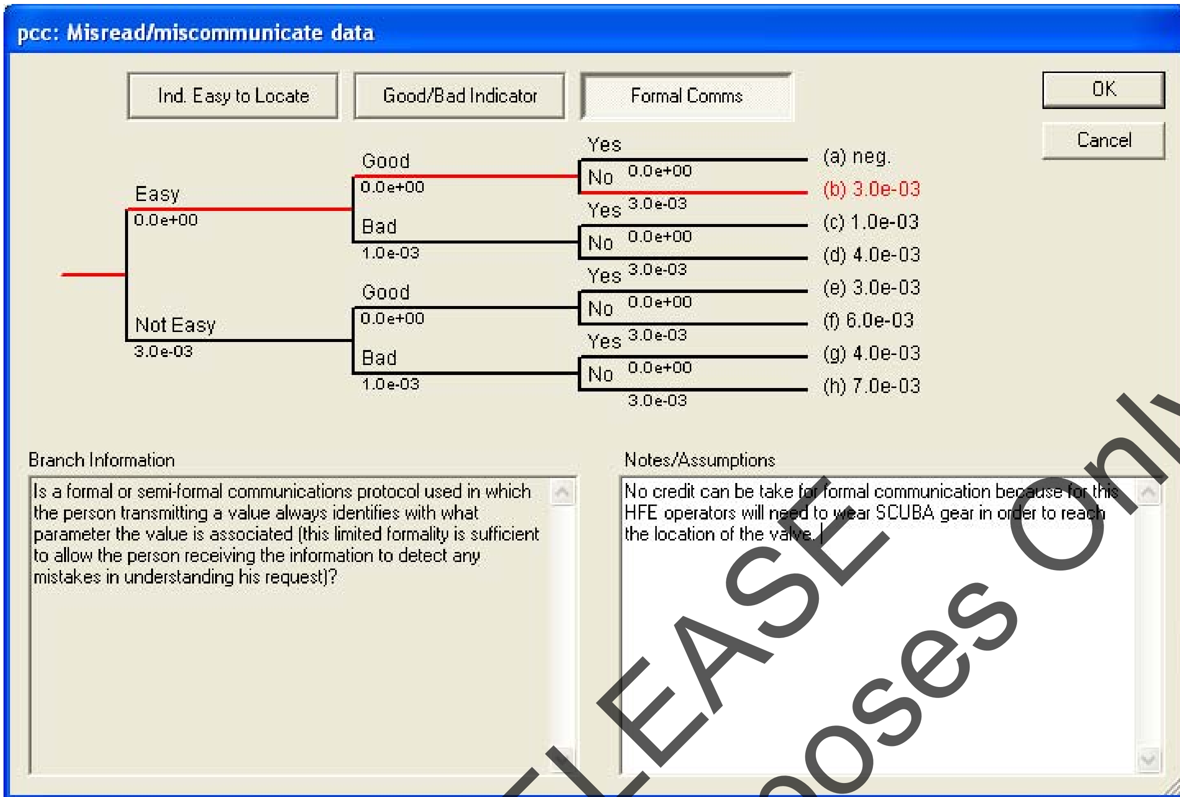


Figure B-18
EPRI HRA methodology p_cc: branch selection to account for difficulties in communication

B.7.3.4 Failure Mechanism d: Information Misleading

Guidance on Failure Mechanism *d* is shown in Figure B-19, Table B-9, and Figure B-20.

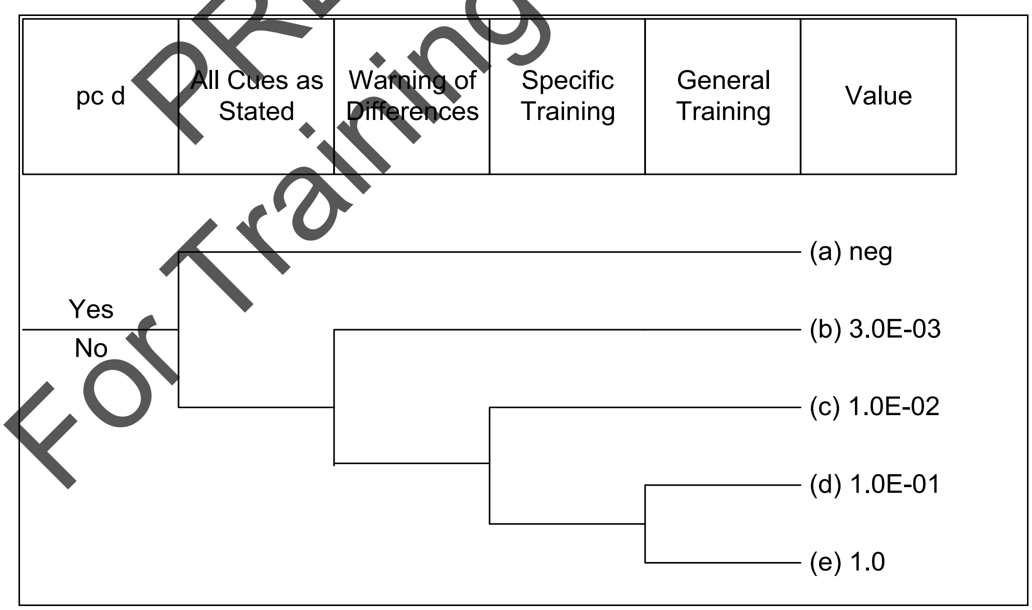


Figure B-19
Decision tree p_cd: information misleading

Table B-9
Guidance on decision nodes for p_cd: information misleading

Decision Node	Guidance as Stated in EPRI TR-100259 [2]	Guidance Specific for Fire HRA
All Cues as Stated	Are cue states or parameter values as stated in the procedure? For example, if high steam line radiation is given as one of the criteria for decision or action, the steam line radiation indicators will read high, rather than normal. The *No* branch is to be used if an indicator is not obviously failed but would not give the value stated in the procedure (as it would, for example, if the steam line were isolated).	If the instrumentation is considered to be fully impacted by fire, the *No* branch should be used. If the instrumentation is considered to be partially impacted or not impacted by fire, the *Yes* branch should be used.
Warning of Differences	Does the procedure itself provide a warning that a cue may not be as expected or provide instructions on how to proceed if the cue states are not as stated?	No additional guidance for fire.
Specific Training	Have the operators received simulator training in which the cue configuration was the same as in the situation of interest and that emphasized the correct interpretation of the procedure in the face of the degraded cue state?	Fire-specific training is to be verified by training staff and/or operators.
General Training	Have the operators received training that should allow them to recognize that the cue information is not correct in the circumstances? That is, is it something that every licensed operator is expected to know? For the example of the radiation monitor on the isolated steam line, the answer is *yes* because isolations are so common; for instrument abnormalities that occur only a very special set of circumstances, the answer would be *no* unless the particular situation had received some emphasis in training. Operators cannot be expected to reason from their general knowledge of instrumentation the behavior of a specific indicator in a situation where they are not forewarned and there are many other demands on their time and attention.	Fire-specific training is to be verified by training staff and/or operators.

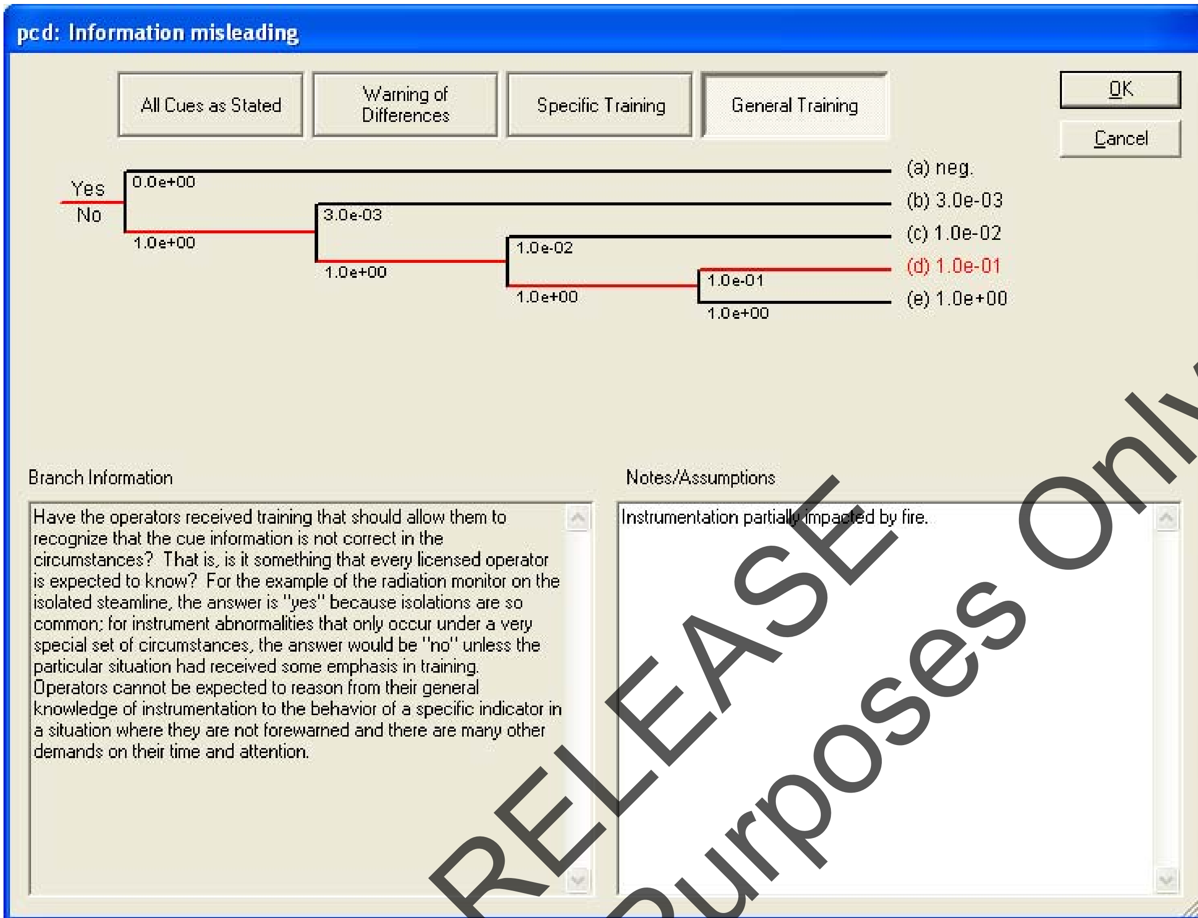


Figure B-20
EPRI HRA methodology p_{cd} branch selection to account for instrumentation partially impacted by fire

B.7.3.5 Failure Mechanism e: Relevant Step in Procedure Missed

Guidance on Failure Mechanism *e* is shown in Figure B-21, Table B-10, and Figure B-22.

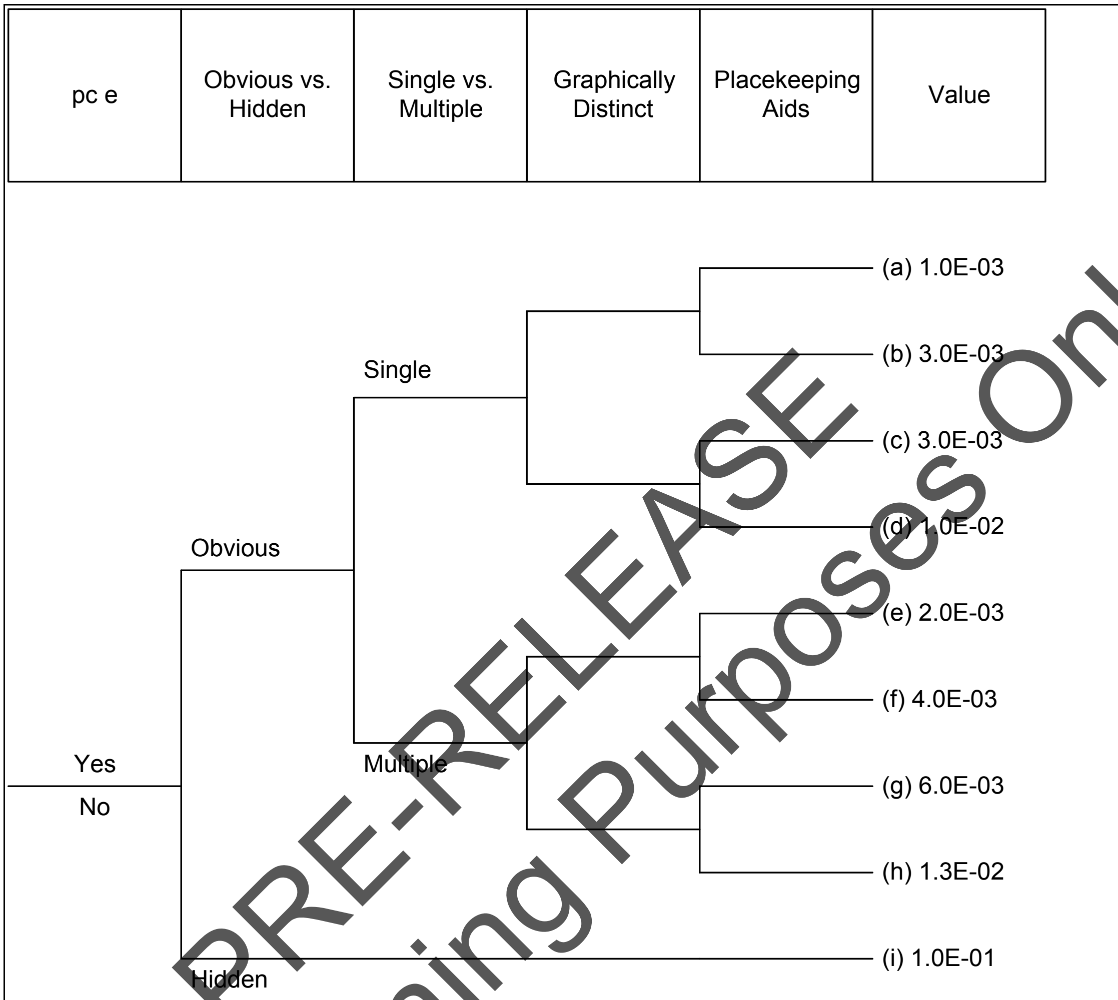


Figure B-21
Decision tree for p_ce: relevant step in procedure missed

Table B-10
Guidance on decision nodes for p_ce: relevant step in procedure missed

Decision Node	Guidance as Stated in EPRI TR-100259 [2]	Guidance Specific for Fire HRA
Obvious vs. Hidden	Is the relevant instruction a separate, stand-alone numbered step, in which case the answer is *Yes* or the upper branch is followed in the decision tree? Or is it "hidden" in some way that makes it easy to overlook, for example, one of several statements in a paragraph, in a note or a caution, or on the back of a page?	No additional guidance for fire.
Single vs. Multiple	At the time of the HI, is the procedure reader using more than one text procedure or concurrently following more than one column of a flowchart procedure? If so, answer with *Yes*, or follow the upper branch in the decision tree. Generally, multiple procedures apply only to BWRs.	If the EOPs are implemented in parallel to the fire procedures, multiple procedures will be in effect.
Graphically Distinct	Is the step governing the HI in some way more conspicuous than surrounding steps? For example, steps that form the apex of branches in flowchart procedures, steps preceded by notes or cautions, and steps that formatted to emphasize logic terms are more eye-catching than simple action steps and are less likely to be overlooked simply because they look different from surrounding steps. However, this effect is diluted if there are several such steps in view at one time (as on a typical flowchart); for this reason, the only steps on flowcharts that should be credited as being graphically distinct are those at the junction of two branching flow paths. A procedure step is considered graphically distinct (as used in p_ce) if it is preceded by a "caution" note, set off in a box, or is the only step on the page.	No additional guidance for fire.
Placekeeping Aids	Are placekeeping aids, such as checking off or marking through completed steps and marking pending steps, used by all crews? The EOPs are written in a columnar "response/response not obtained" format. They may incorporate check-offs and may have provisions for placekeeping. Use of both of these aids would be noted during operator training on the simulator.	No additional guidance for fire.

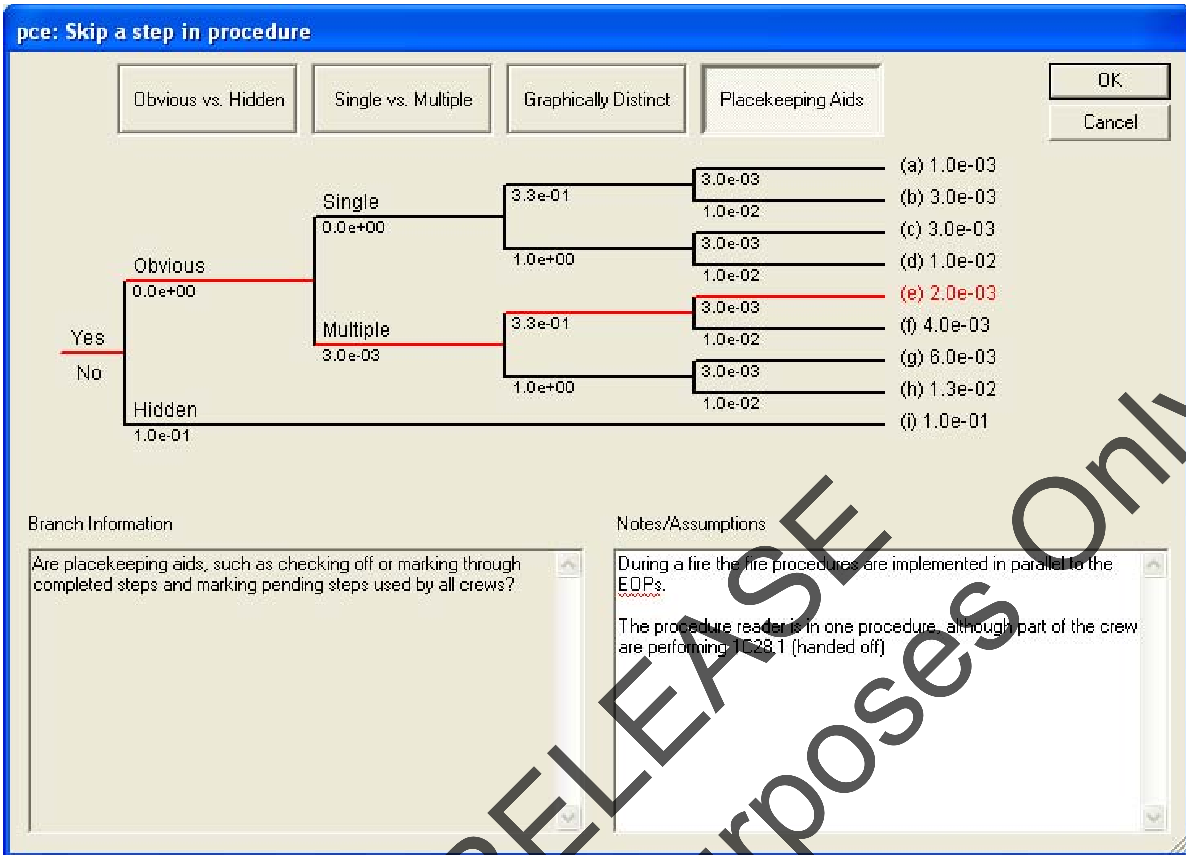


Figure B-22
EPRI HRA methodology p_{ce} branch selection to account for fire procedures used in parallel to EOPs

B.7.3.6 Failure Mechanism f: Misinterpret Instruction

Guidance on Failure Mechanism *f* is shown in Figure B-23 and Table B-11.

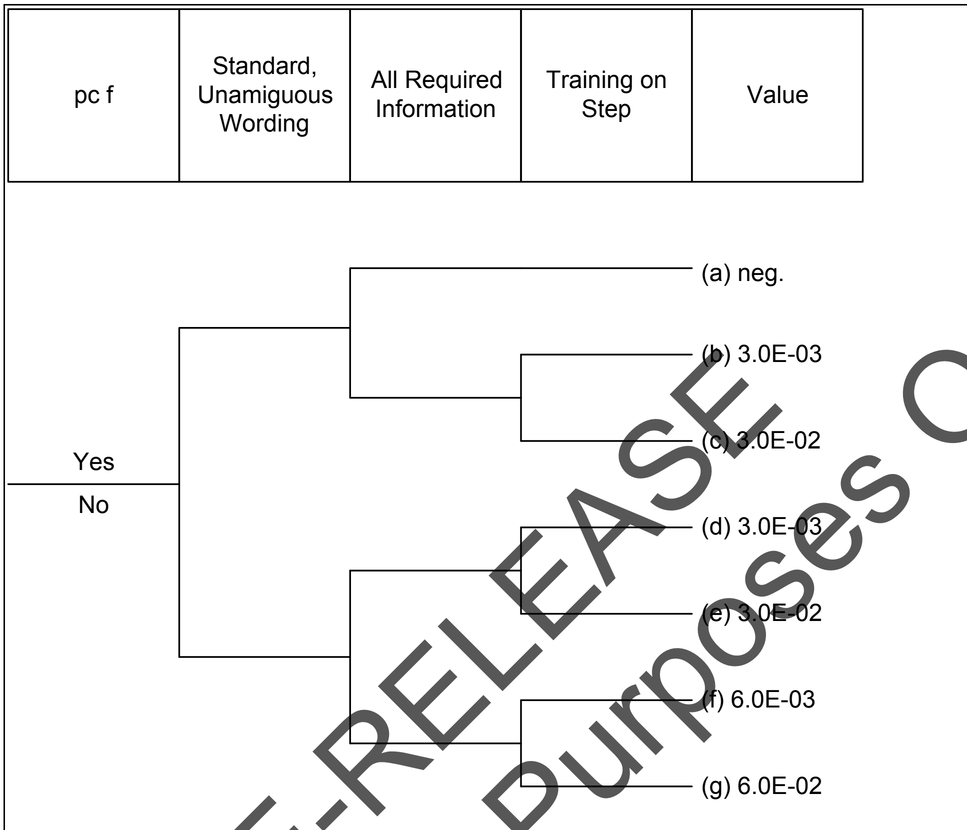


Figure B-23
Decision tree for p_cf: misinterpret instruction

Table B-11
Guidance on decision nodes for p_cf: misinterpret instruction

Decision Node	Guidance as Stated in EPRI TR-100259 [2]	Guidance Specific for Fire HRA
Standard Unambiguous Wording	Does the step include unfamiliar nomenclature or an unusual grammatical construction? Does anything about the wording require explanation in order to arrive at the intended interpretation? Does the proper interpretation of the step require an inference about the future state of the plant? Standard wording = Yes, Ambiguous; Unusual = No.	No additional guidance for fire.
All Required Information	Does the step present all information required to identify the actions directed and their objects?	
Training on Step	Has the crew received training on the correct interpretation of this step under conditions similar to those in this HI?	

B.7.3.7 Failure Mechanism g: Error in Interpreting Logic

Guidance on Failure Mechanism *g* is shown in Figure B-24 and Table B-12.

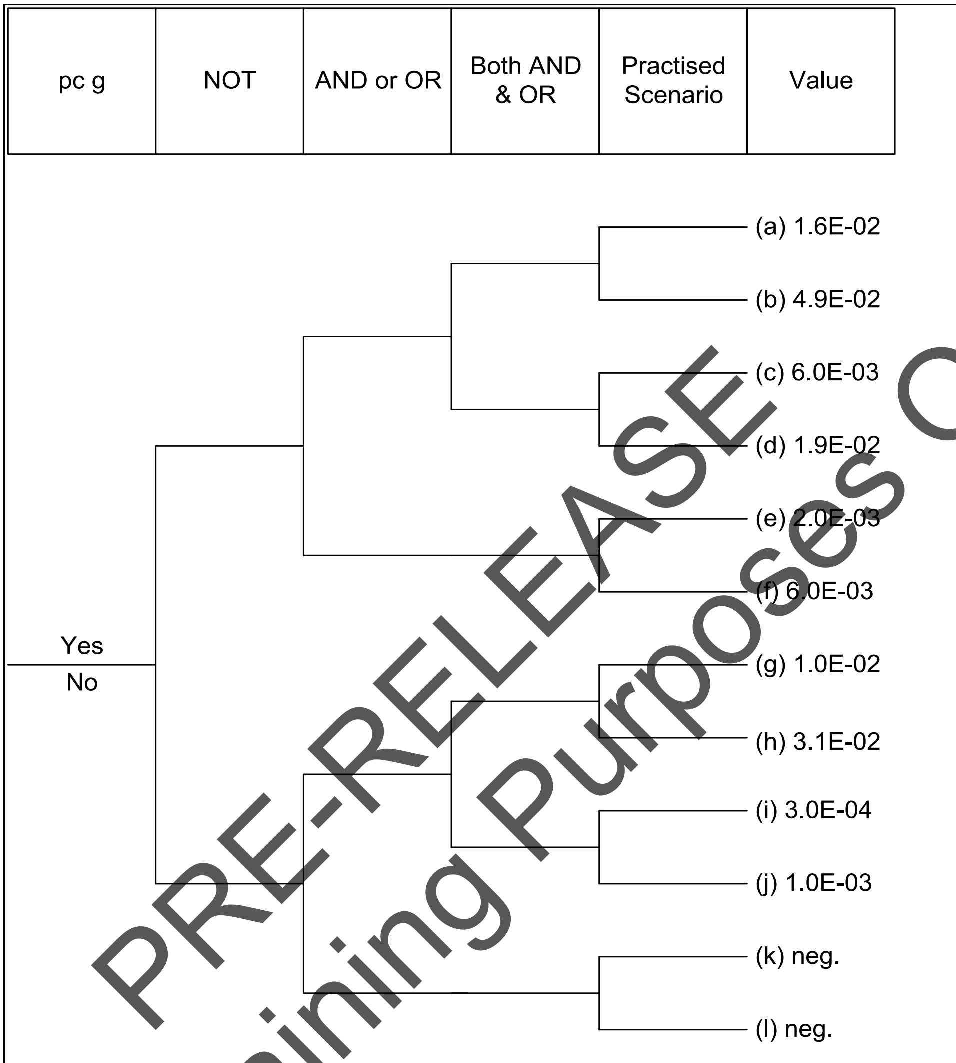


Figure B-24
Decision tree for $p_c g$: error in interpreting logic

Table B-12
Guidance on decision nodes for p_cg: error in interpreting logic

Decision Node	Guidance as Stated in EPRI TR-100259 [2]	Guidance Specific for Fire HRA
NOT Statement	Does the step contain the word *not*?	No additional guidance for fire.
AND or *OR* Statement	Does the procedure step present diagnostic logic in which more than one condition is combined to determine the outcome?	
Both *AND* and *OR*	Does the step contain a complex logic involving a combination of *AND* and *OR* terms?	
Practiced Scenario	Has the crew practiced executing this step in a scenario similar to this one in a simulator?	

B.7.3.8 Failure Mechanism h: Deliberate Violation

Guidance on Failure Mechanism *h* is shown in Figure B-25 and Table B-13.

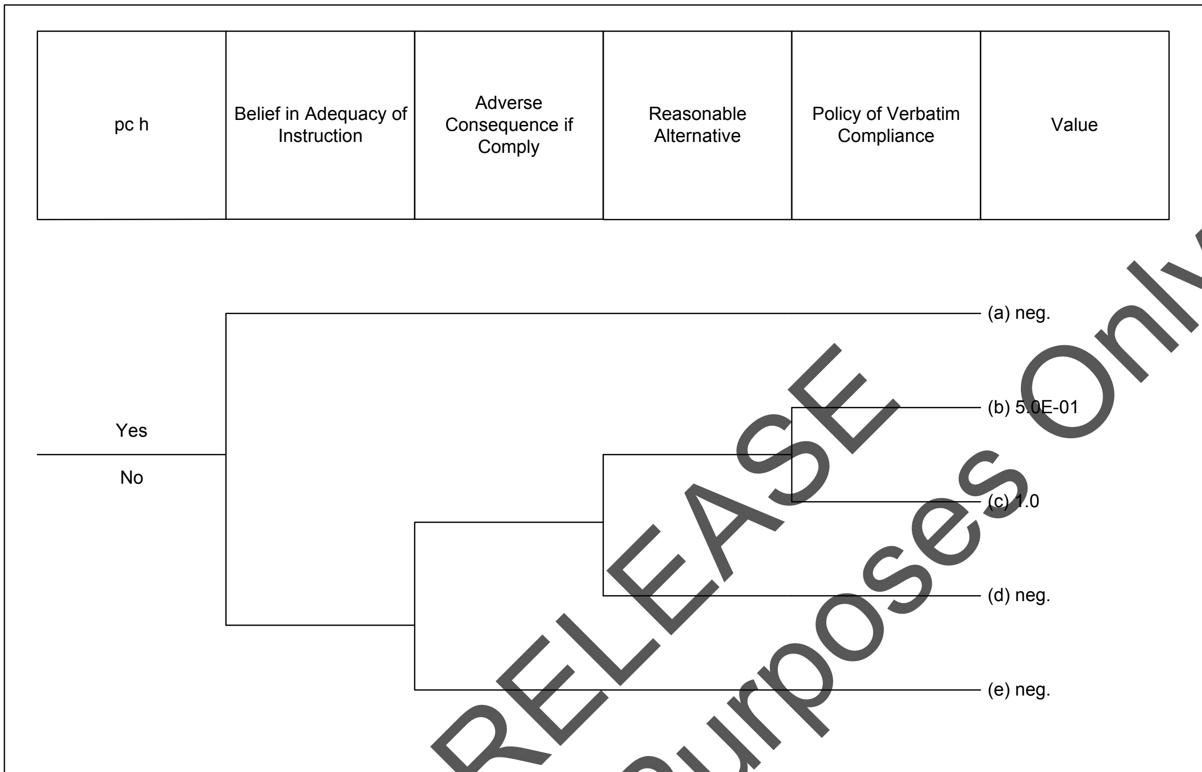


Figure B-25
Decision tree for p_ch: deliberate violation

Table B-13
Guidance on decision nodes for p_ch: deliberate violation

Decision Node	Guidance as Stated in EPRI TR-100259 [2]	Guidance Specific for Fire HRA
Belief in Adequacy of Instruction	Does the crew believe that the instructions presented are appropriate to the situation (even in spite of any potential adverse consequences)? Do they have confidence in the effectiveness of the procedure for dealing with the current situation? In practice, this may come down to whether they have tried it in the simulator and found that it worked.	No additional guidance for fire.
Adverse Consequence if Comply	Will literal compliance produce undesirable consequences, such as release of radioactivity, damage to the plant (e.g., thermal shock to the vessel), unavailability of needed systems, or violation of standing orders? In the current regulatory climate, a crew must have strong motivation for deliberately violating a procedure.	
Reasonable Alternatives	Are there any fairly obvious alternatives, such as partial compliance or use of different systems, that appear to accomplish some or all of the goals of the step without the adverse consequences produced by the step as written? Does simply delaying implementation appear to offer a reasonable hope for averting undesirable consequences? Note that simply delaying all or part of the response may not be considered a violation if the response is ultimately executed successfully.	
Policy of "Verbatim" Compliance	Does the utility have and enforce a policy of strict verbatim compliance with EOPs and other procedures?	

B.7.3.9 CBDTM Cognitive Recovery

The EPRI HRA methodology uses the following rules based on crew availability for determining which recovery factors can be applied to each CBDTM decision tree:

- If T_{delay} is greater than the shift length, shift change can be credited.
- If T_{sw} is greater than or equal to ERF activation time, ERF review can be credited.
- If T_{sw} is greater than or equal to 15 minutes, STA review can be credited.
- The self-review and extra crew do not have time thresholds but should not be credited for extremely time-limited cases, such as when the time required equals the time available.

Multiple recoveries to a single decision tree are permitted by the CBDTM method. The dependency levels are applied to each recovery individually; the recoveries are then multiplied to obtain the value shown in the *Multiply By* column in Figure B-26. The dependency values are calculated using THERP.

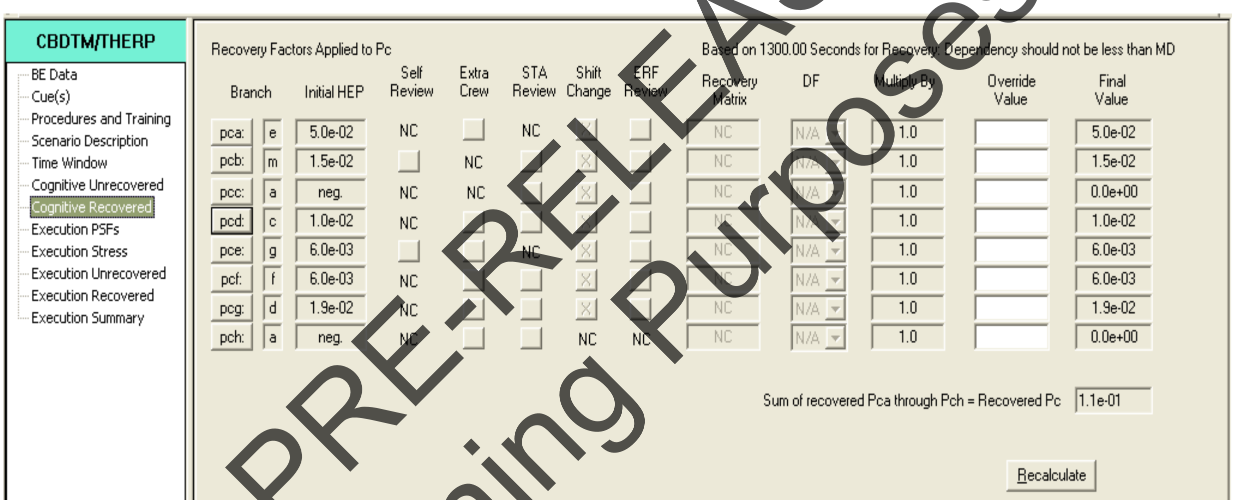


Figure B-26
Cognitive recovery

For existing EOP actions, the dependency levels may need to be increased from the base case if the timing available has decreased. If the dependency level is below the minimum recommended level set by the EPRI HRA methodology, the DF column shown in Figure B-26 will be red.

If the base case applies multiple recoveries to decision trees p_ca and p_cd and the scenario being modeled involves impact on instrumentation, the recoveries need to be reevaluated.

For fire response actions, the assignment for recoveries follows the same process as for internal events HRA.

B.7.4 Cognitive Modeling Using HCR/ORE

The HCR/ORE is an empirical method that relies on time-reliability correlations. The crew non-response probability in this case represents the probability that an operating crew, while making the correct decision, takes too much time in comparison with the time available to respond. This contribution to the crew overall non-response is particularly important for situations in which a relatively fast response to a cue must be made. The HCR/ORE then forms a function based on the normalized time (i.e., the dimensionless unit that reflects the ratio of time available to crew median response time) of the probability of crew non-response. Each non-response curve is characterized by two crew response time parameters: a crew median response time ($T_{1/2}$) and a logarithmic standard deviation of normalized time (σ). With these two parameters, the probability of crew non-response (P_c) in a time window ($T_{1/2}$) is given as follows:

$$P_c = 1 - \Phi\ [\ln(T_w/T_{1/2})/\sigma]$$ **Equation B-1**

where:

Φ = the standard normal cumulative distribution (refer to standard normal distribution tables)

T_w = (T_{sw} - T_m - T_{delay}) = time available for cognitive response

T_{sw} = the system time window available (time to an irreversible damage state such as equipment damage, or the time to core damage [CD]).

T_m = the manipulation time, that is, the time required to complete the needed actions once they are identified. This is inclusive of the time needed to don special gear, travel (if necessary) to location of action and perform then action; it is equivalent to T_{exe} defined in Section 4.6.2.

$T_{1/2}$ = the crew median response time.

σ = the logarithmic standard deviation

The timing information is defined in the same way for all methods in the EPRI HRA methodology. For fire HRA, the timing adjustments described in the timing sections apply directly to the HCR/ORE method.

The crew median response time ($T_{1/2}$) is based on the best-estimate response time and not the more conservative, bounding time typically used for T_{cog}. The crew median response time consists of detection, diagnosis and decision-making. If there is a wide distribution on the data points used to derive $T_{1/2}$ and calculate P_{cog}, then response time should be considered as a key source of uncertainty and an upper bound sigma applied (see below).

Sigma (σ) corresponds to the variability in operator response and is determined from Table 3-1 in Reference [2]. It is based on the type of reactor (either PWR or BWR) and the HFE categorizations CP1, CP2, or CP3. It must be noted that P_c is based on the assumption that time window T_{sw} is a constant (i.e., no uncertainty).

The σ represents the crew-to-crew variability in responding to a specific cue. For internal events HRA, the analyst has the option to use the average σ, the lower (10^{th} percentile), or the upper (90^{th} percentile) bound. For internal events, most EOP-driven HFEs use the average sigma. The

lower bound can be used for cases in which there is little crew variation expected such as the initial response to a reactor trip.

For fire response actions that are proceduralized in the fire procedures, the average sigma is used when it has been confirmed by operator interviews that operators will use and believe in the adequacy of the fire procedures. If there is uncertainty about when and/or how the fire procedures will be implemented, the upper bound sigma is used. For typical U.S. plants, the main control room (MCR) abandonment criteria are defined to be at the discretion of the shift manager, shift technical advisor (STA), or other high-level manager; this is an example of a situation in which the upper bound could be used.

Table B-14 shows the corresponding sigma values to be used for fire HRA.

Table B-14
Estimates of average sigma with upper and lower bounds

Plant Type	HI Category	Average σ	Standard Deviation (Note 1)	Lower Bound (Note 2)	Upper Bound (Note 3)
				10th Percentile	90th Percentile
BWR	CP1	0.7	0.18	0.40	1.00
	CP2	0.58	0.23	0.20	0.96
	CP3	0.75	0.10	0.59	0.91
PWR	CP1	0.57	0.19	0.26	0.88
	CP2	0.38	0.19	0.07	0.69
	CP3 (Note 4)	0.77	**	0.5	1.2

Note 1: The standard deviation was calculated from data presented in EPRI TR-100259 [2]. The values shown in Table B-14 are those used in the EPRI HRA Calculator as well as those listed in Table 3-1 of EPRI TR-100259. There is an error in the notes of EPRI TR-100259: the formula used to determine sigma is stated as being the 95^{th} percentile, but the formula shown and used in the calculation is for the 90th percentile.

Note 2: Lower bound 10th percentile σ = average σ -1.64 X (standard deviation of the sample of σs).

Note 3: Upper bound 90th percentile σ = average σ +1.64 X (standard deviation of the sample of σs).

Note 4: For PWR CP3 actions, there is only one data point in the original data set; therefore, no distribution can be calculated. Instead, overly conservative estimates are presented and are to be used with caution.

B.7.5 Execution Modeling

Execution is modeled in the EPRI HRA methodology using THERP.

B.7.5.1 Execution PSFs

The execution PSFs explicitly modeled in the EPRI HRA methodology are shown in Figure B-27.

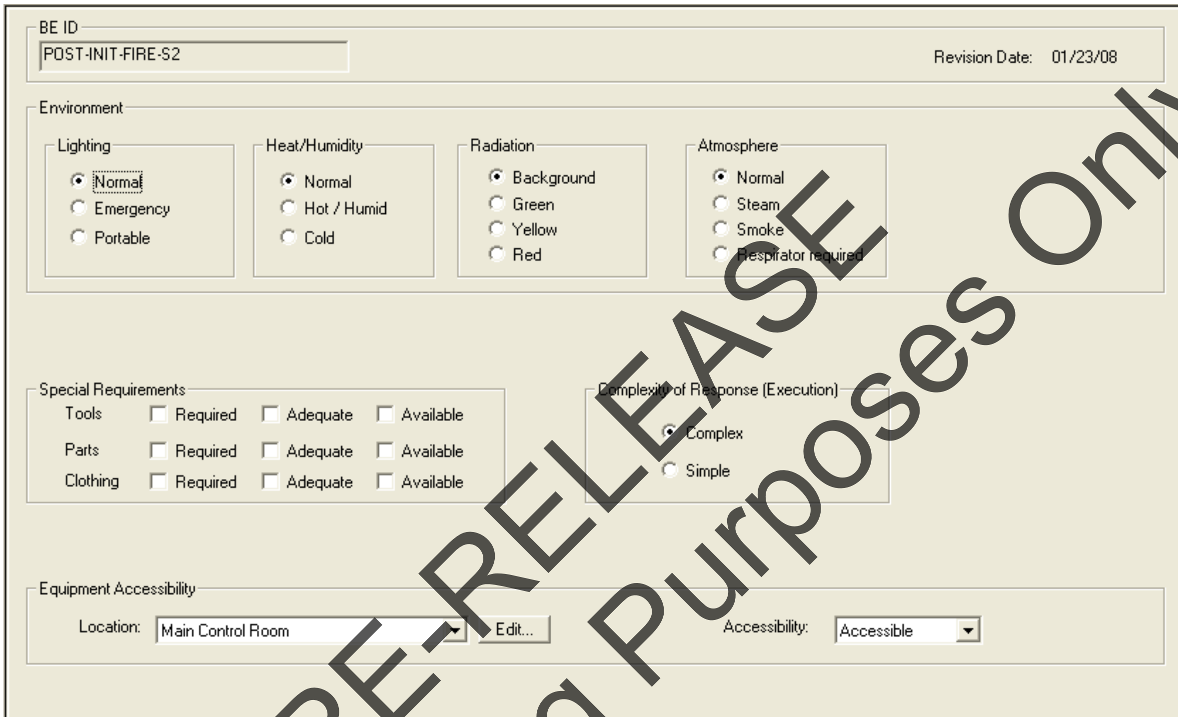


Figure B-27
EPRI HRA methodology execution PSFs

For fire HRA, if the smoke will impact the operators, the smoke PSF should be checked. Consequently, the stress level will be at least moderate to high.

If the operators have to travel through an area in which the fire has impacted accessibility, the *accessibility* field should be set to, at a minimum, *with difficulty*. If the location of the action is inaccessible because of the fire, HEP should be set to 1.0.

In the EPRI HRA methodology, if any one of the PSFs shown above is considered negative, the stress (determined in execution stress) should be at least moderate.

B.7.5.2 Execution Stress

Execution stress is determined by a decision tree (shown in Figure B-28) based on workload and execution PSFs. The stress level is used as a direct multiplier to the execution probabilities; within the EPRI HRA methodology, the following multipliers are used:

- Low stress: PSF=1
- Moderate stress: PSF=2
- High stress: PSF=5

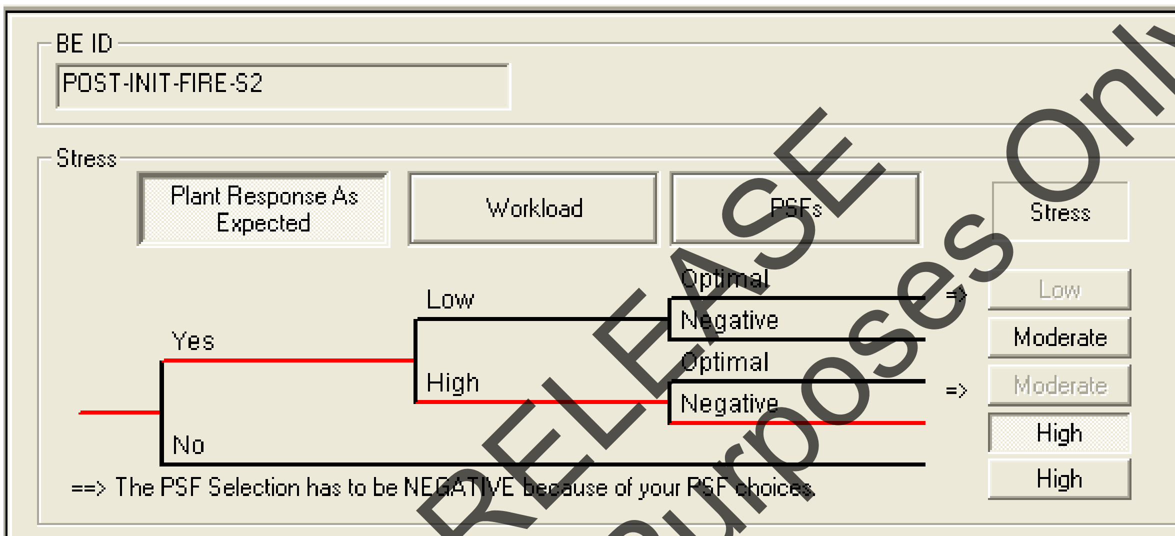


Figure B-28
EPRI HRA methodology execution stress

The selection of stress level should be consistent with how it is determined for internal events HRA. The fire may cause elevated stress initially and in the long term if the operators do not perceive the plant conditions to be improving. For control room actions, the stress level may or may not be elevated. The level of stress would be dependent on the control room PSFs.

B.7.5.3 Execution

The execution is quantified using THERP [3].

The actual values used for the execution HEPs of the individual error modes are clearly situation specific and are determined based on an interpretation of the instructions in THERP [3]. Quantification of the execution portion of each HEP is based on THERP data and techniques. The various tables in THERP's Chapter 20 are used in determining the HEPs for the subtasks that make up the operator action. The most commonly used THERP tables are Table 20-7 for errors of omission (EOM) and Table 20-12 for errors of commission (EOC).

Median HEP values from THERP are converted to mean values to be consistent with the requirements of the ASME/ANS PRA Standard [7] and applied as point estimates. An error factor is assigned to each human failure event, based on the resultant HEP using THERP Table 20-20.

The following modeling conventions are used in determining P_e and apply to both fire HRA and internal events HRA:

1. For control room actions, only proceduralized recoveries are credited initially. For local actions (EOP directed actions outside the control room), a recovery is considered if the completion of the local action—or lack of completion—produces a "compelling signal" in the control room. (For example, completing the local valve lineup for refueling water storage tank (RWST) refill using the chemical and volume control system (CVCS) boric acid blender actuates the boric acid and primary water totalizers on the main control board.)
2. Execution errors are calculated using the THERP tables. For errors of omission, the values from Table 20-7 can be divided by 3 based on notes in THERP Chapter 15 for those procedures that are structured similar to current plant EOPs, specifically, that they are symptom-based and/or follow the "response/response not obtained" format. The notes to THERP Chapter 15 describe adjustments to the nominal values, in particular to credit the improved layout and clarity of procedures. For fire procedures that are not structured similar to current EOPs (such as if they are not symptom based and/or do not use the "response/response not obtained" format), the EOM values in THERP Table 20-7 are used directly and are not reduced by a factor of 3.
3. The application of recovery is included when it is judged that there is enough time for revisitation, based on the sequence timing and time available for the human interaction. See Item #7 for additional details on the impact of timing on dependencies.
4. In modeling recovery, the recovery factor should be a procedural step and is typically modeled as the EOM (from Table 20-7) for the procedure step with the EOC modeled as a failure to read the associated instrument.
5. In determining the EOM p_e values, if the human interaction takes place within 10 procedural steps from the start of the procedure, Item 20-7(1) (short list, with check-off provisions) from THERP is used. If the human interaction takes place >10 steps into the procedure, Item 20-7(2) (long list, with check-off provisions) is used. Items 20-7(3) and 20-7(4) (no check-off provisions) are usually used when the procedure is not an EOP. The start of the procedure is used instead of the start of the accident sequence based on policies for the control room supervisor to conduct a brief and thus re-synchronize the entire crew upon transfer of procedures.
6. Table 20-13 from THERP is for local manual valve operation. This table is also applied to the operation of other local components such as switchgear breakers and room doors.
7. The dependence between elemental HEPs in the subtasks that make up each p_e is handled using the dependency rules in THERP:
   - If a human interaction required two of two manipulations for success, p_e includes HEPs for EOC(1) + EOC(2).
   - If a human interaction required one manipulation with two switches available, failure to manipulate the first switch can be recovered by operating the second switch: EOC(1) * EOC(2).

Tables B-15 and B-16 show how the p_e is quantified within the EPRI HRA methodology.

Table B-15
Example of THERP modeling: execution unrecovered

Procedure: ES 1.3, Transfer to Cold Leg Recirculation		Comment				Stress Factor	Override
Step No.	Instruction/Comment	Error Type	THERP Table	THERP Item	HEP		
E-1.3 Step 4 RNO	Locally close 8804 A (73-ft RHR access)					5	
	--	EOM	20-7b	4	4.3E-3		
		EOC	20-13	1	1.3E-3		
						Total Step HEP	2.8e-02
E-1.3 Step 8	Check for charging pp amps, charging injection flow, and SI pp flow if pumps (pps) are in operation					5	
	--	EOM	20-7b	4	4.3E-3		
		EOC	20-11	4	3.8E-3		
						Total Step HEP	4.1e-02

Table B-16
Example of THERP modeling: execution recovered

Critical Step No.	Recovery Step No.	Action	HEP (Crit.)	HEP (Rec)	Dep.	Cond. HEP (Rec)	Total for Step
E-1.3 Step 4 RNO		Locally close 8804 A (73-ft RHR access)	2.8e-02				2.5e-03
	E-1.3 Step 8	Check for charging pp amps, charging injection flow, and SI pp flow if pps are in operation		4.1e-02	LD	8.9e-02	
		Total Unrecovered	**2.8e-02**			**Total Recovered**	**2.5e-03**

B.7.6 Summary of Modeling Existing EOP Actions within the EPRI HRA Methodology

For existing EOP actions, it is necessary to make only small modifications from the base HFE for quantifications. The previous sections covered all of the required steps to quantify and document a fire HFE using the EPRI HRA methodology. For existing EOP actions, most of this information will be the same for both the base case HFE and fire HFE. Table B-17 summarizes the previous sections and shows what needs to be modified between a base case HFE and fire HFE. Table B-17 is applicable only to existing EOP actions in which the definition has not been changed for fire modeling. A HFE whose definition was changed due to the fire impact on the plant context would need to be re-defined after capturing the impacts of the fire damage on the plant. For example, the fire HFE may require the action to be performed in the context of a different, fire-induced initiating event than was modeled for the existing EOP action.

Table B-17
Potential changes to consider when updating internal events HFEs for fire

Internal Events HFE Data	Changes to Consider When Updating Internal Events HFEs for Fire
Cues	If not previously documented, include the component ID in the cue identification field. Additionally, the fire impacts on instrumentation are to be noted.
Procedures and training	No changes are needed. This assumes that the expected procedure response is the same for both the response to a fire and to internal events scenario.
Operator interviews	Document fire-specific insights from operator interviews.
Manpower requirements	No changes are needed as a preliminary quantification.
Time window	If the implementation of the EOPs is delayed due to the performance of the fire procedure(s), the delay time is systematically increased by the average time it would take to perform the fire procedure(s)—typically about 30 minutes. In this case, $T_{delay} = T_{delay\ base\ case} + 30$ min. If an action is a local action, the T_m may need to be increased to account for the additional time it could take for the operators to get to the location due to detours caused by the fire. The travel delay is highly dependent on the fire location. If it is not known how the fire will directly affect the operators' travel, it is recommended that T_m be increased by 10 minutes from the base case. The 10 minutes is used as an estimated value; if the action is determined to be risk-significant, this value will need to be verified and/or justifiable in the context of the fire scenario. If the time available for recovery is less than or equal to zero, set the HEP evaluates to 1.0 because there is insufficient time to perform the action.

Table B-17
Potential changes to consider when updating internal events HFEs for fire

Internal Events HFE Data	Changes to Consider When Updating Internal Events HFEs for Fire
Cognitive unrecovered CBDTM	Decision tree P_ca: If the fire fully impacts the instrumentation such that indications are not available, the HEP evaluates to 1.0. If the instrumentation is partially impacted by fire, the indications are not considered accurate. If no instrumentation is impacted by fire, no modifications are made to this tree. Decision tree P_cb: If the EOPs are implemented in parallel to the fire procedures, the workload is considered to be high. Decision tree P_cc: If SCBA is required due to fire, communications are considered poor. Decision tree P_cd: If the fire fully impacts the instrumentation, cues are not available and the HEP evaluates to 1.0. If instrumentation is partially impacted, cues are not as stated, but credit can be taken for general and/or specific training. If the fire has no impact on instrumentation, the cues are not impacted by fire. Decision tree P_ce: If the EOPs are implemented in parallel to fire procedures, multiple procedures are used. Decision tree P_cf: No modifications are needed for fire. Decision tree P_cg: No modifications are needed for fire. Decision tree P_ch: No modifications are needed for fire.
Cognitive recovered CBDTM	If the time was modified due to fire, the recoveries need to be reevaluated to ensure that the minimum level of dependency is met. If the instrumentation is partially impacted by fire and recoveries have previously been applied to decision trees P_ca and P_cd, the recoveries need to be reconsidered.
Cognitive HCR/ORE	For fire HRA for existing internal events actions, the same sigma value is used for internal events. $T_{1/2}$ should be adjusted to account for any additional diagnosis time required to address instrumentation impacts. If the fire impacts all instrumentation, cues are not available and the HEP evaluates to 1.0.
Execution PSFs	Check to ensure that, for local actions, the location is still accessible in spite of fire. If not accessible, HEP = 1.0. For fire scenarios that impeded communications or if smoke is present such that it will impact operator performance, the stress should be moderate or high.
Execution stress	The evaluation of stress should be consistent with how it is applied for internal events.
Execution unrecovered	No changes are needed.
Execution recovered	No changes are needed.

B.7.7 Summary of Modeling Fire Response Actions within the EPRI HRA Methodology

The theory and parameters to consider for modeling fire response actions are the same as those for existing EOP actions. Sections B.1 through B.6 are applicable to all types of HFEs. For fire response actions, there is no internal events action to use as a base analysis, so the HRA analyst must evaluate each input parameter. Table B-18 summarizes the key parameters that are unique to fire response actions.

Table B-18
Fire-specific parameters used in the EPRI HRA methodology

EPRI HRA Methodology	Fire-Specific Parameters to Include in HFE Analysis
Basic event data	In the Related Human Interaction Field, the analyst should include both fire response actions and any EOP actions that are occurring in the same scenario. In many cases, the fire response actions are performed as a recovery to an internal events action.
Cues	The Cue field includes documenting the specific instrumentations, and any instrumentation impacted by fire should be noted. For fire response actions, the cue may be a step in the fire procedures. If operator interviews confirm that the operators intend to follow the fire procedures step by step, crediting the step in the fire procedure as the cue would be appropriate. However, often the operators state during operator interviews that they will not follow the procedures step by step and instead use them for additional information. In this case, the cue would need to be something that alerts the operators to at least check the procedures. Simply using the step in fire procedures would be inappropriate.
Procedures and training	If the fire procedures are implemented in parallel to the EOPs, both the fire procedure and the EOPs are to be referenced. For fire response actions, it is important to understand how the crew will use the fire procedures and the EOPs. This is critical to developing the timeline.
Operator interviews	Document insights from operator interviews. The operator interviews include discussion on the expected usage of the fire procedures. Are the fire procedures implemented in parallel to EOP actions? Do the operators intend to use the fire procedures, and do they believe in the adequacy of the fire procedures? Typically, two rounds of operator interviews are needed—the first to understand the general fire response and the second to talk through fire-specific detailed scenarios.
Manpower requirements	The manpower requirements are evaluated for the minimum number of people available during the back shift and the minimum number of staff available following the detection of a fire.
Time window	For local actions, the manipulation time (TM) should account for travel time to reach the location, including any detours due to the fire location. If the time available for recovery is less than or equal to zero, the HEP should evaluate to 1.0 because there is insufficient time to perform the action.

Table B-18
Fire-specific parameters used in the EPRI HRA methodology (continued)

EPRI HRA Methodology	Fire-Specific Parameters to Include in HFE Analysis
Cognitive unrecovered CBDTM	Decision tree P_ca: If the fire fully impacts the instrumentation, indications are not available and the HEP evaluates to 1.0. If the instrumentation is partially impacted by fire, indications are not considered accurate. If no instrumentation is impacted by fire, no modifications are made to this tree. Decision tree P_cb: If the EOPs are implemented in parallel to fire procedures, the workload is considered to be high. Decision tree P_cc: If SCBA is required due to fire, communications are considered poor. Decision tree P_cd: If the fire fully impacts the instrumentation, the cues are not available and HEP evaluates to 1.0. If instrumentation is partially impacted, cues are not as stated, but credit can be taken for general and/or specific training. If the fire has no impact on instrumentation, the cues are not impacted by fire. Decision tree P_ce: If the EOPs are implemented in parallel to fire procedures, multiple procedures are used. Decision tree P_cf: Use the same guidance as for internal events. Decision tree P_cg: Use the same guidance as for internal events. Decision tree P_ch: Use the same guidance as for internal events.
Cognitive recovered CBDTM	Use the same guidance as for internal events.
Cognitive HCR/ORE	For fire response actions that are proceduralized in the fire procedures, the average sigma is used when it has been confirmed by operator interviews that operators will use and believe in the adequacy of the fire procedures. If there is uncertainty about when and/or how the fire procedures will be implemented, the upper bound is used.
Execution PSFs	For fire response actions, a high stress level should be used if any of the execution PSFs is negative. Ensure that, for local actions, the room is still accessible in spite of fire. If components required for manipulation are not accessible due to fire, the HEP evaluates to 1.0.
Execution stress	The evaluation of stress should be consistent with how it is applied for internal events.
Execution unrecovered	Use the same guidance as for internal events.
Execution recovered	Use the same guidance as for internal events.

B.7.8 Summary of Modeling MCR Abandonment Actions within the EPRI HRA Methodology

MCR abandonment actions are considered a subset of fire response actions. At most U.S. nuclear plants the MCR abandonment procedure is an abnormal operating procedure (AOP) and is implemented in the same manner as all other AOPs. Therefore, the actions can be quantified in the same manner as AOP actions. The same guidance for fire response actions (see Table B-18) can be applied to MCR abandonment actions.

B.7.9 Summary of Modeling Undesired Operators Response Actions within the EPRI HRA Methodology

The EPRI approach for identifying undesired operator response actions is presented in Section 3 of this report. The following assumptions were made in the identification process:

- Actions that require multiple spurious indications on different parameters can be screened from consideration.
- Actions that require indication on one of several redundant channels can be screened from consideration. If the action requires multiple spurious indications on redundant channels, the actions cannot be screened from consideration.
- Actions that have a proceduralized verification step can be screened from consideration.

For quantification, the EPRI approach is not suitable to quantify the probability that the EOC will not occur. Instead, the EPRI approach assumes that the EOC has occurred and then models a recovery action. If the recovery action is proceduralized in the fire procedures, the guidance for fire response actions can be applied. If the recovery action is a proceduralized EOP action, the existing EOP guidance can be applied.

B.8 Modeling Fire Effects Using the EPRI Methods

Because the EPRI methods are symptom based—not initiator based—the way in which the specific fire effects described in Section 4.3 are incorporated into the EPRI approach is not always obvious. This section discusses each PSF described in Section 4 and how it is addressed for fire HRA. However, PSFs are never considered independently. For example, the cues could impact timing, and procedures could impact cues. Where appropriate, this section attempts to capture some of the PSF overlap specific for fire and focus on how fire-specific scenarios could be addressed. The PSF overlap is situation specific, and the HRA analyst must have a qualitative understanding of the scenario and the EPRI approach before quantification. It is outside the scope of this appendix to reproduce all guidance related to the HRA methodology and applied methods such as THERP [3], CBDTM [2], HCR/ORE [1], and SHARP/SHARP1 [4].

B.8.1 Cues and Indications

Cue and indications can be mapped to the following parts of the EPRI approach:

- Considered explicitly in decision trees $p_c a$ and $p_c d$.
- Cues are identified and documented in the *Cue* field within the HRA methodology.
- The time at which the operators receive the cues is used as an input to T_{delay}.
- The time it takes for the operators to interpret the cues is considered in $T_{1/2}$.

The *Cue* field within the HRA methodology includes documenting the specific instrumentation, and any instrumentation impacted by fire are noted in this field. For HFE analyses that have been carried over from the internal events analysis, this field confirms that the cues and indications credited for internal events actions are still valid. For example, an operator action taken in response to certain indications credited in the internal events PRA may not still be credible if the indications are impacted by the fire or if the associated instrumentation cable routing is unknown.

For discussion purposes, there are three categories of potential instrumentation impacts on fire HFEs:

- No impact: all required instrumentation is available.
- Partial impact: a minimum set of the required instrumentation is available and considered accurate. For this case, some of the instrumentation can be failed by the fire or spuriously actuating, giving false indications.
- Total impact: less than the minimum set of required instrumentation is available. All instrumentation required for diagnosis is failed by the fire.

The following examples illustrate the way in which impacted cues are modeled.

For an internal events case, consider an action in which all SG level indicators are available and reliable. For the internal events case, the branches in decision trees p_{ca} and p_{cd} are used, and the impacts on cognition are considered negligible (see Figure B-29).

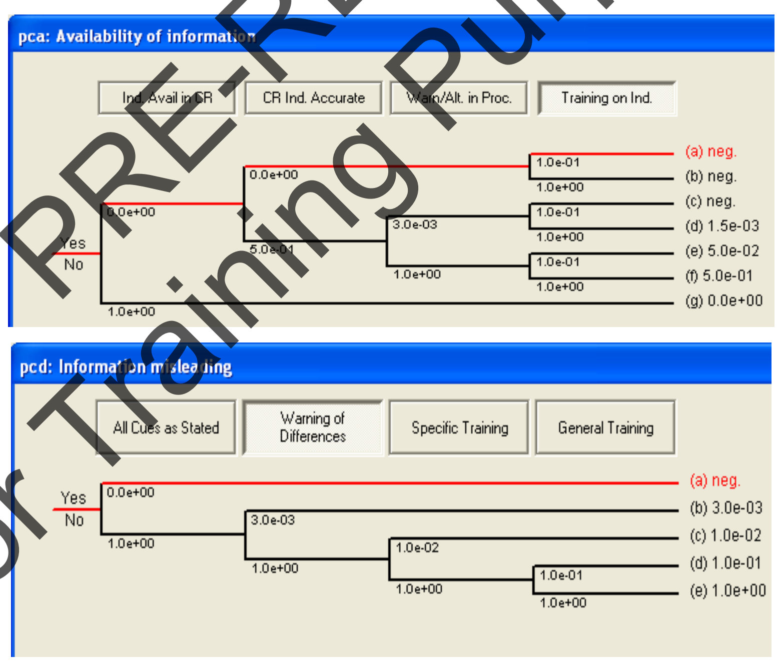


Figure B-29
Modeling of SG level indicators for internal events action in which there is no impact on instrumentation

Consider the same action for the fire case. However, in the fire case, two of four SG level indicators are failed by the fire, and the choices shown in Figure B-30 are applied. In the fire case, all instrumentation required for successful cognition is available in the control room, but half of the instrumentation is failed by fire and therefore considered inaccurate. Not all of the cues are as stated because the operators must determine which level indicators are correct. In this fire scenario, the sum of decision trees $p_{c}a$ and $p_{c}d$ is 1.5E-1 with no recoveries applied.

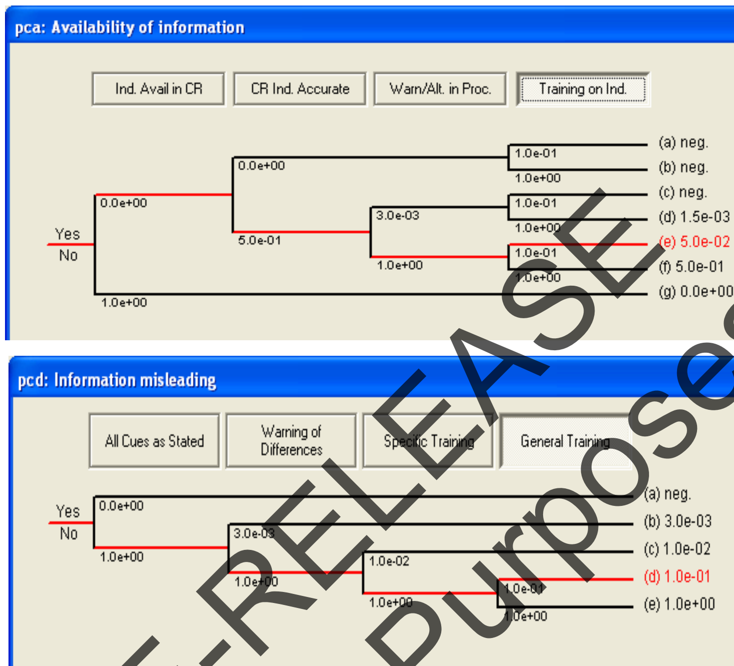


Figure B-30
Modeling to reflect partial impact on instrumentation due to fire effects

For fire response actions, the cue may be a step in the fire procedures. If operator interviews confirm that the crew intends to follow the fire procedures step by step, crediting the step as the cue in the fire procedure would be appropriate. However, there are many cases in which the operators will state during operator interviews that they will not follow the procedures step by step and instead use them for additional information. In this case, the cue would need to be something that alerts the operators to at least check the fire procedures. Simply using the step in fire procedures would be inappropriate.

For the partial instrumentation impact case, identification and interpretation of the invalid indications could be time consuming and, in the worst case, cause the operators not to take the required actions within the time available. The time it would take for the operators to interpret and react to a partial instrumentation case is captured in $T_{1/2}$. In some cases, because of a combination of spurious and failed indications, the diagnosis is so complex that $T_{1/2}$ is estimated to take longer than the total time available to complete the action. In this case, the HEP would evaluate to 1.0.

B.8.2 Timing

B.8.2.1 Timing for Fire HFEs

The EPRI HRA method applies the following definitions for *time*:

- T_{sw} = system time window; typically the time from reactor trip (T=0) to an undesired end state
- T_{delay} = time from T=0 until cue is reached
- T_m = manipulation time
- $T_{1/2}$ = median response time

The *Timing Analysis* field documents the source of the timing in accordance with ASME/ANS PRA Standard Requirements HR-G4 and HR-G5 [7].

T_{delay}, $T_{1/2}$, T_{sw}, and T_m are used as inputs to crediting recoveries in CBDT decisions trees and the HCR/ORE correlation.

For fire HRA, T_{sw} is based on the defined accident sequence modeled in the fire PRA. For risk-significant actions, this time is based on realistic generic thermal-hydraulic analysis or simulation from similar plants in order to meet PRA Standard Requirement HR-G4.

If the dependency analysis module within the HRA methodology is applied, all HFEs must be aligned such that T=0 is the same starting point. It is good practice to set T=0 as the start of the fire: there may be cases in which the fire starts but does not require a reactor trip, and no fire impacts are identified for several minutes. This fire growth time would be modeled in T_{delay}.

T_{delay} represents the time at which the cue is received. This time is a function of the fire and also takes into account any procedure delay caused by the fire. If the implementation of the EOPs is delayed because of the performance of the fire procedure(s), the delay time for all existing internal events HFEs is systematically increased by the average time it would take to perform the fire procedure(s) — typically about 30 minutes. In this case, $T_{delay} = T_{delay\ base\ case} + 30$ min.

$T_{1/2}$ is best obtained by simulator observations. For scenarios in which no instrumentation is impacted by fire, the $T_{1/2}$ time would be similar to the internal events time because the EOPs are symptom based—not initiator based—and it is expected that the operators will trust their instrumentation unless there is a compelling reason not to. For cases in which the cues are partially impacted by the fire, the diagnosis may not be clearly identified in the procedures. These are the cases in which simulator observation would be the most beneficial.

For fire response actions, the diagnosis will typically be made in the control room and the execution local; therefore, it would still be possible to observe a $T_{1/2}$ time from simulator observations. If there is a need to model local cognition, $T_{1/2}$ can be obtained by talk-throughs and walk-throughs.

The manipulation time (T_m) accounts for any of the following fire effects:

- **Travel time to reach the execution location.** The fire may cause the operators to detour around the most direct route to perform local actions. It is assumed that the operators will not travel directly through a fire location. However, operators can travel through a smoky area to reach the local action. The travel time could be significantly impacted by the fire location. As an initial estimate for existing internal events HFEs, it is recommended that T_m be increased by at least 10 minutes. If the HFE is risk-significant, this time should be verified.
- **Time to don self-contained breathing apparatus (SCBA) and the additional time SCBA would take to perform the actions.** The time to don SCBA can be observed during annual SCBA training; however, in training, operators do not feel time pressure—and therefore this observed timing could be conservative. For HFEs that require SCBA gear, it should be ensured that there is enough time to perform the action even with a conservative estimated time to don gear.
- **The presence of smoke.** If the operators cannot clearly see the valve they need to open, there may be additional time involved in locating the correct valve, thus increasing T_m.

In some cases, the fire procedures specifically state that the local actions must be required within a specified time. This time can be used as a preliminary estimate for T_{sw} or T_m. It can be used for T_m if it is expected that the time does not include diagnosis and detection. For risk-significant actions, the time for manipulation will need to be based on walk-throughs and talk-throughs with operators.

NUREG-1792 [6] and NUREG/CR-6850 [5] point out that timing can be influenced by many other PSFs. In particular, the time to perform an action is a function of (at least) the following factors that could be impacted by fire. The discussions that follow consider only the PSFs and how they relate to time; discussion of how each of the PSFs is addressed in the EPRI approach is provided in other parts of this appendix.

- **Crew.** The HRA methodology addresses the number of crew required in the *Manpower* field. If there is not enough crew to perform all required operator actions in the fire sequence within the total time available, the HEP = 1.0.

  The crew is also considered in the timeline development. Within the CBDT, additional crew can be credited as recoveries. During a fire, the technical support center (TSC) will typically be activated within 2 hours of the start of the fire and can be credited for actions that occur later (after the TSC is actuated) in the scenario.

  The variation in crew response is characterized within the HCR/ORE by the use of sigma. The more expected variation among crews, the higher the sigma value. For EOP actions, limited crew variation is expected.
- **Human-machine interface (HMI).** The manipulation time accounts for the time it would take for the operators to interact with the plant, that is, open a valve or start a pump. $T_{1/2}$ also accounts for the time it would take for the operators to interpret or locate cues. For example, if the operators have to go to the back of the control room to read an indication, the $T_{1/2}$ would be longer than if the indicators are located on the front panel.
- **Complexity of action involved.** $T_{1/2}$ accounts for complexity in diagnosis: the more complex the diagnosis, the longer it will take to make a correct one. T_m accounts for the complexity of the action: the more complex an action, the longer it will take to complete.

- **Special tools or clothing.** Putting on SCBA gear is considered part of T_m. Additionally, T_m accounts for locating and using special equipment such as ladders or keys.
- **Diversions and other concurrent requirements.** Competing tasks can influence $T_{1/2}$ because the operators will be distracted and could take longer to diagnose the need for the action. This could also impact T_{delay} because it could take the operator longer to receive the cue. For example, if the cue is a step in the fire procedures and the operators do not refer to the fire procedures immediately following the reactor trip but instead enter EOPs, T_{delay} accounts for the time it takes for the operators to get into the fire procedures.
- **Procedures.** The procedure usage will impact all aspects of timing. T_{delay} is based on when the operators receive the cues; if the cue is a procedure step, T_{delay} must account for the total time to perform all previous steps in the sequence. If the procedures are ambiguously worded, it would take the operators longer to make the diagnosis. This is reflected in $T_{1/2}$. The manipulation time must account for the total time it takes to perform all of the procedure steps. There could be several proceduralized steps that are not required for success, but the operators will still perform these actions—leading to longer times to reach the final steps in the procedure.
- **Environmental conditions.** Environmental conditions may slow the operators' response time; this is accounted for in T_m.

The EPRI HRA methodology uses the following rules based on crew availability for determining which recovery factors can be applied to each CBDTM decision tree:

1. If Tdelay > shift length, Shift Change can be credited.
2. If Tsw ≥ ERF activation time, ERF Review can be credited.
3. If Tsw ≥ 15 minutes, STA Review can be credited.
4. The self-review and extra crew are not time-based recoveries.

NUREG/CR-6850 [5] provides the following examples of how the overall estimates of the time available and time needed to complete the desirable action can be influenced by other PSFs during a fire. These scenarios are used to show how timing is applied within the HRA methodology to model fire effects.

Scenario 1: A spurious closure of a valve used in the suction path of many injection paths may need quick detection and response by the crew. For this example, assume that the following PWR scenario is given. The cue is an annunciator, and the operators have 30 minutes to open the valve after the start of the fire before the pumps cavitate due to loss of suction. The fire causes a spurious closure of the valve but does not impact instrumentation. Operator interviews were conducted; the operators stated that they anticipate the following sequence of events: trip the reactor, enter E-0, and disperse the fire brigade. After they ensure that they have a transient and the plant is stable (i.e., no safety injection [SI] and no station blackout), they start reviewing annunciators. This scenario was observed in the simulator to determine the sum of the timing. In this scenario, T_{sw} = 30 minutes by definition of the fire sequence, T_{delay} = 0 because the loss of suction occurs at the start of the fire, and the annunciator is received at the start of the fire. $T_{1/2}$ was observed to be 5 minutes; this time accounts for the operators not acknowledging the annunciators within the first 4 minutes because they were busy dispersing the fire brigade and working in E-0. When the operators do acknowledge the alarm, they immediately send an

operator to locally open the valve. A walkdown was performed; it took the operator 5 minutes to reach the valve location with no fire impacts. (For this case, assume that the fire has no impact on travel time.) A time for opening the valve cannot easily be measured because of plant operations; however, during outages, this valve is regularly opened and the operators estimate that it takes 2–5 minutes to do so (approximately 30 turns). In this case, T_m = 5 minutes for travel time and 5 minutes to open the valve—the total T_m is therefore 10 minutes.

The following scenario would be input into the HRA methodology as shown in Figure B-31.

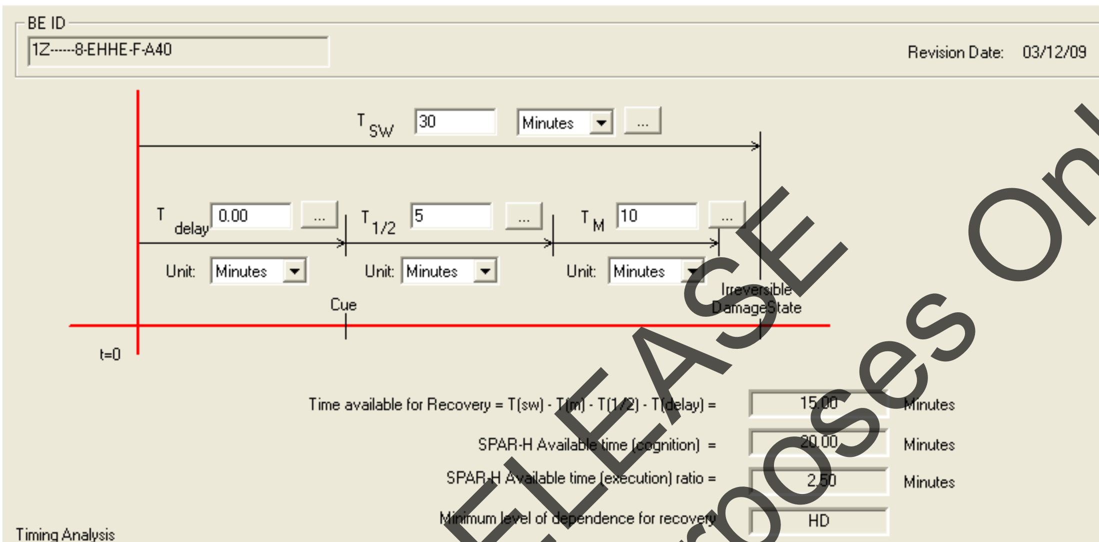


Figure B-31
Modeling for timing scenario 1

This timing information is used directly in HCR/ORE [1], and the results are shown in Figure B-32. This action is a CP1. Average sigma is used because this is an EOP action, and it is expected that the crew variation will be limited because the scenario models a well-trained proceduralized path with no impact on instrumentation. For a sensitivity case, the upper bound can be used.

Plant Type	Response Type	LB	Sigma	UB
BWR	CP1	0.4	0.7	1
	CP2	0.2	0.58	0.96
	CP3	0.59	0.75	0.91
PWR	CP1	0.26	0.57	0.88
	CP2	0.07	0.38	0.69
	CP3		0.77	

Figure B-32
Modeling of HCR/ORE for Scenario 1

Within the CBDT, no recoveries are applied for cognition because only one operator is performing the annunciator panel review for this scenario.

Scenario 2: Interfacing with the fire brigade may delay performing some actions. Fire HRA does not model fire brigade response directly, but interaction with the fire brigade could impact the timing. For example, at some plants, members of the on-shift operating crew become members of the fire brigade; at other plants, the fire brigade is a separate, independent team.

For illustrative purposes, assume that upon diagnosis of a fire, a local reactor operator (RO) is assigned to join the fire brigade. In this case, the local RO would not be available to perform tasks directed by the control room until the firefighting is complete. The additional time to locate a secondary person would be modeled as an increase in T_m.

B.8.2.2 Timing for MCR Abandonment Actions

For MCR abandonment scenarios, the timeline is difficult to model. T_{delay} accounts for the time at which the control room would receive the cues and consider abandoning. If the scenario involves smoke in the control room, T_{delay} would be the time at which the smoke reaches a specified level. For a loss-of-control scenario, T_{delay} represents the time at which all control is lost. This time may not necessarily be at T=0.

$T_{1/2}$ is the time from which the cue for abandonment is received until the operators make the decision to abandon. There will always be uncertainty in this time, and typically a sensitivity analysis can be done to establish a bounding case. Because it would be difficult to demonstrate this in the simulator, this value is typically an HRA analyst's best judgment.

Unlike $T_{1/2}$, T_m can be observed; typically the MCR abandonment procedure is an AOP and is trained on annually. Depending on the plant, JPMs may be available to obtain an estimate of the manipulation time. However, training and JPMs are not necessarily performed using SCBA gear or addressing local fire effects such as smoke. Given a fire in a specific location, the operators' travel paths can be timed, and any detours caused by fire can be measured.

Because of the expected large crew-to-crew variation associated with the point at which the operators abandon the control room, the upper bound for sigma should be considered when using the HCR/ORE correlation.

B.8.3 Procedures and Training

Procedures guidance is identified and documented in the *Procedure* field in the HRA methodology. Procedures are considered explicitly in decision trees p_ca, p_cd, p_ce, p_cf, p_cg, and p_ch and to model EOMs for execution. They are implicitly used in quantification to identify the cues for cognition and the critical task for execution and to develop the timeline.

As stated in NUREG-1852 [8], there are three roles of plant procedures that can aid in successful operator performance during a fire:

1. The procedures can assist the operators in correctly diagnosing the type of plant event that the fire may trigger (usually in conjunction with indications), thereby permitting the operators to select the appropriate operator manual actions.
2. The procedures direct the operators to the appropriate preventive and mitigative manual actions.

3. The procedures attempt to minimize the potential confusion that can arise from fire-induced conflicting signals, including spurious actuations, thereby minimizing the likelihood of personnel error during the required operator manual actions. Written procedures contain the steps required; unless the steps can be argued to be skill-of-the-craft, the procedures should also contain guidance on how and where the steps should be performed and the tools or equipment that should be used.

These roles are addressed within the HRA methodology as follows:

- Failures in the operator-procedure interface for diagnosis are modeled in decision trees p_ce, p_cf, p_cg, and p_ch. The way in which the operators interact with the procedures will impact the probability of failure to correctly diagnose the action.
- Procedure usage specifically for execution is credited using THERP. The critical tasks and proceduralized recoveries are to be identified, and each critical task is assigned an EOM and EOC.
- Decision tree p_ca addresses procedure usage to assist the operator if the instrumentation is unreliable. The fire may cause the instrumentation to be unreliable because it is either failed by the fire or providing spurious readings. For cases in which there is partial impact on instrumentation, a warning in the procedure can be credited as having a positive impact on diagnosis.

Decision tree p_cd also considers procedure usage to assist the operator if the instrumentation is unreliable. The *All Cues as Stated* branch addresses whether the cues are providing the correct readings. The fire may cause the instruments to spuriously actuate, causing false readings. In this case, the cues listed in the procedures would not be stated. The fire procedure may alert the operators that an instrument can spuriously actuate, and the procedure warning is addressed in the second branch.

If the EOPs are implemented in parallel to the fire procedures, the workload is assumed high; this is modeled in decision tree p_cb. However, if the cue for the action occurs after the fire has been extinguished, the workload is assumed to decrease.

Decision tree p_ce also addresses the use of multiple procedures and the effects of working two procedures at once. If the EOPs are implemented in parallel to the fire procedures, multiple procedures will be in effect, and the *Multiple Procedures* branch is used. In cases in which the fire procedures are implemented prior to the EOPs, the workload could still be considered high if there are multiple fire procedures or if multiple attachments are used at the same time.

In some cases, especially for some ex-control room (CR) actions, procedures might not exist or be readily retrievable or ambiguous. The analyst needs to perform checks of the adequacy and availability of these other procedures that would be needed to address the fires modeled in the fire PRA. Obviously, the amount of training the crews receive on implementing the procedures and the degree of realism will be critical factors.

For cases in which no procedures exist, the important aspect to consider is the cue used for diagnosis. In these cases, decision trees p_cd, p_ce, p_cf, and p_cg would not be applied, and decision trees p_ca, p_cb, and p_cc will become more important for cognition. For execution, the EOM would typically come from following verbal instructions from memory.

In cases in which the procedure is ambiguously worded, the lower branch on decision tree p_cf is used. There are very few cases of ambiguously worded procedure steps in the EOPs. The fire procedures, however, often have cases of ambiguously worded procedures, such as the example presented in Table B-19.

Table B-19
Example of ambiguously worded procedure (Fire Zone 100) intake structure

Affected Equipment	Available Equipment
1. SW	
ASW Pps 1-1 and 1-2	ASW Pp 1-1 will remain available.
ASW Gates 1-8 and 1-9	ASW Gates 1-8 and 1-9 will not spuriously close.
2. HVAC	
ASW Pp Rms: E-101 and E-103	E-103 will remain available.

In the example in Table B-19, it is not clear why the same equipment appears in both the *Affected* column and the *Available* column, and the *Ambiguously Worded Procedure* branch would be applied.

As with procedures, training for both control room and local actions is an important factor in assessing operator performance. As stated in NUREG-1852 [8], training serves three supporting functions for operator performance during a fire:

- Training establishes familiarity with the fire procedures and equipment needed to perform the desired actions as well as potential conditions in an actual event.
- Training provides the level of knowledge and understanding necessary for the personnel performing the operator manual actions to be well prepared to handle departures from the expected sequence of events.
- Training gives personnel the opportunity to practice their response without exposure to adverse conditions, enhancing confidence that they can reliably perform their duties in an actual fire event.

For internal events HRA, typically operators can be considered "trained at some minimum level" to perform their desired tasks. This is modeled in the CBDT decision trees by always selecting the *Yes* branch for training. For fire HRA, the crew's familiarity and level of training (e.g., the types of scenarios, frequency of training or classroom discussions, and frequency of simulations) for addressing the range of possible fire compilations and potential actions to be performed may not be the same as for internal events. "Less familiarity" needs to be accounted for in assessing the impact of training for fire actions and in determining their HEPs. The less familiarity is accounted for in decision trees p_ca, p_cd, p_cf, and p_cg. Most plants provide some general training on the use of the fire procedures. In this high-level training, the operators are trained to be aware of false instrumentation, but there is no scenario-specific training. Decision trees p_ca, p_cg, and p_cd address general training, and decision trees p_cd and p_cf address scenario-specific training. Scenario-specific training includes addressing fire effects. The decision tree training is considered a recovery to another PSF, such as poor procedure wording, failed or misleading instrumentation, or distractions due to workload.

The type and frequency of training are identified and documented in the *Training* fields within the HRA methodology. Training is considered explicitly in decision trees p_ca, p_cd, p_cf, and p_cg.

B.8.4 Complexity

As stated in NUREG-1792 [6], the PSF complexity attempts to measure the overall complexity involved for the situation at hand and for the action itself (e.g., many steps have to be performed by the same operator in rapid succession versus one simple skill-of-the-craft action). Many of the other PSFs bear on the overall complexity, such as the need to decipher numerous indications and alarms, the presence of many and complicated steps in a procedure, and/or a poor HMI. Nonetheless, this factor should also capture “measures,” such as the ambiguity associated with assessing the situation or in executing the task, the degree of mental effort or knowledge involved, whether it is a multi- or single-variable associated task, whether special sequencing or coordination is required for the action to be successful (especially if it involves multiple persons in different locations), and whether the activity may require sensitive and careful manipulations by the operator.

For quantification, complexity is not addressed explicitly for quantification within the EPRI HRA approach. Within the HRA methodology, the HRA analyst must qualitatively assess the complexity of the action as simple or complex, both for cognition and execution, in order to meet PRA Standard Requirement HR-G3 Category I. In general, the more complex the operator action, the higher the HEP. For quantification, the EPRI approach addresses cognition complexity and execution complexity issues, which together define *complexity*.

B.8.4.1 Cognition Complexity

There are very few EOP actions that would require complex diagnosis because EOPs are symptom based and do not require the operator to make a diagnosis of the initiator for success. The assumption with the EOPs is that if the operators follow the procedures, they will be successful. For fires, the cues and indications can be misleading, making the diagnosis more complex. Poor cues and indications are modeled in decision trees p_ca and p_cd. Additionally, if the cues and indications are impacted by the fire, it will take the operators longer to make the correct diagnosis; this is reflected in the $T_{1/2}$ value. Procedure usage for fire response is considered *complex* if the operators must interpret the instructions because of unclear wording. Ambiguous wording is modeled in decision tree p_cf. Additionally, the use of the fire procedures is not always straightforward, which would lead to an increase in T_m. Sometimes the use of the procedure is left to the discretion of the operators; in this case, there will be a greater variation among crew, and the upper bound for sigma can be used in the HCR/ORE.

For cognitively complex actions, additional crew may be credited in the CBDT decision trees because it is assumed that the more crew available to assist, the greater the success. Extra crew members, STA, and TSC can all be credited to assist in a complex diagnosis as long as enough time is available.

B.8.4.2 Execution Complexity

The following are indications of execution complexity:

- **Single versus multiple procedure steps.** If an action requires only a single task, it is considered less complex than if multiple steps are required. The more critical tasks required, the longer it will take to perform the actions—which impacts T_m. Using THERP, each critical task is assigned a failure probability; the more tasks required, the higher the failure probability.
- **Multiple crew members performing coordinated steps.** If multiple crew members are required to complete an action and the steps require coordination and communication among team members to successfully complete the action, the higher the complexity. If the action involves oral instructions among crew members, THERP Table 20-8 is used for selecting an EOM. If a crew member must report to other members after completing a task, an additional critical task of reporting is included and modeled as an EOM using either THERP or ASEP.
- **Multiple location steps.** During the execution of an action, multiple locations may need to be visited either by different members of the staff or by one staff member. The necessity of visiting multiple locations (e.g., different electrical cabinets or different rooms, not just different panels in the MCR) increases the complexity, particularly if coordination and communication among the staff members are required. Generally, if multiple locations must be visited to complete the action, high complexity is assumed. Visiting multiple locations requires a longer execution time, and this is modeled by increasing T_m. The more locations involved, the more critical tasks required—thus, by definition, there are more EOCs and EOMs that can result in a high failure probability.
- **Multiple functions.** Multiple functions may need to be performed in the execution of an action (e.g., both aligning and controlling flow) that will increase the execution complexity of the action. For each function identified, an EOC value is applied using THERP; for example, *failure to open valve – EOC* is selected from THERP Table 20-13 for local action, and *failure to monitor flow – EOC* would be selected from THERP Table 20-11. If both opening and monitoring are required, the sum of both EOCs is used.
- **Accessibility of location or tools.** Factors such as excessive heat, absence of adequate lighting, or the presence of the fire brigade in the area may make it more difficult for the operator to reach the location of the actions or to access tools necessary to perform the action. To the extent that the action would become more difficult to complete because of such conditions, high complexity should be assumed. Within the HRA methodology, the HRA analyst must identify these items; if any single PSF is present, the stress level is set to high. Additionally, accessibility will impact the manipulation time, and it is always ensured that there is enough time to complete this action.

B.8.5 Workload and Stress

Workload is considered explicitly in decision tree p_cd when modeling cognition and in the stress decision tree when modeling execution.

Although workload, pressure, and stress are often associated with complexity, the emphasis here is on the amount of work a crew or individual must accomplish in the time available (e.g., task load) along with their overall sense of being pressured and/or threatened in some way with

respect to what they are trying to accomplish (see Swain and Guttmann [3] for a more detailed definition and discussion of stress and workload). The extent to which crews or individuals expect to be under high workload, time pressure, and stress is generally thought to have a negative impact on performance (particularly if the task being performed is considered complex). For fires, if the operators are simultaneously working in both the EOPs and the fire procedures, the workload is considered high. For execution, if the workload is considered high, the stress level is set to either *high* or *moderate*. If the number of required tasks equals or exceeds the number of personnel, work load would be *high*. Time-critical actions may also be perceived as high workload by the operators. Operator interviews will need to be performed to determine whether the operators expect to feel time pressure because of a fire.

Within the EPRI approach, stress quantitatively impacts execution only. For diagnosis, PSFs that make up stress—such as workload, training, procedures, and cues and indications—are considered explicitly and described previously. The stress level determined in the stress decision tree is reflected as a direct multiplier to the execution using the values shown in Table B-20.

Table B-20
Stress PSF values

HRA Methodology Stress Level	Multiplier to P_{exe}
Low	1
Moderate	2
High	5

The first branch of the decision addresses whether the operators believe that the plant is responding as expected. For fire scenarios that involve a transient with no instrumentation impacts, the plant would be responding as expected. The spurious actuation of equipment is not expected, and, if the fire scenario involves spurious actuation, the *No* branch would be used. Another example would be if the operators lose control from the control room because of fire impacts and MCR abandonment is required.

If any one of the following PSFs is considered poor because of the fire, the *PSF* branch of the stress decision tree is considered negative:

- Poor lighting.
- Heat or smoke due to the effects of the fire. It is assumed that the HRA analyst has assessed qualitatively that even though smoke is present, the action can still be completed.
- Radiation levels are above normal ambient radiation.
- SCBA is required.
- Special tools or clothing are required.
- Radio communication is required.
- Accessibility is limited.

If there is not enough time to complete the actions because of any one of these PSFs, the HEP should evaluate to 1.0.

B.8.6 Human-Machine Interface

Human-machine interfaces (HMIs) impact operator performance differently, depending on the location of the action. In general, NUREG/CR-6850 [5], NUREG-1852 [8], and NUREG-1792 [6] all agree that for control room actions, the HMI will have a minimal or positive effect on human performance. This is because problematic HMIs have either been taken care of by control room design reviews and improvements or are easily worked around by the operating crew as a result of the daily familiarity of the control room boards and layout. However, any known very poor HMI should be considered a negative influence for an applicable action even in the control room. For control room actions for fire HRA, the HMIs will remain similar to internal events with the exception of potential impacts on instrumentation.

CBDT addresses HMI issues in decision trees $p_{c}a$, $p_{c}b$, and $p_{c}c$. For most control room internal events actions, these decision trees evaluate to negligible values. For fire HFEs, this may not be the case if the cues and indications are affected by the fire (see the previous discussion on cues).

For actions that require local diagnosis, decision tree $p_{c}c$ could be important because the local indications may not be easy to locate and, when located, they could be partially impacted by the fire. For MCR abandonment actions, the remote shutdown panel is a good example of where the indicators may not be easily identified.

For the execution of control room actions, the HMI is considered negligible; this is reflected in the selection of THERP values for EOC. Typically, for control room actions that require manual control, THERP Table 12-20 is applied.

Fire response actions may require the operators to manipulate valves or switches that are not typically modeled in internal events. Considering that these valves may not be manipulated as often, not all of the HMI issues may have been addressed. All unclearly or ambiguously labeled valves (i.e., part of a group of two or more valves that are similar in all of the following: size and shape, state, and presence of tags) are addressed in the selection for the EOC using THERP. THERP Table 12-13, Item 5 (HEP = 1.3E-2) is used for the EOC for unclearly or ambiguously labeled valves.

B.8.7 Environment

Within the HRA methodology, environmental impacts are considered in the stress level. If the fire does not directly impact the control room, the environmental conditions inside the control room are not usually relevant to the success of operator actions because they rarely change control room habitability. However, if the fire directly affects the MCR by smoke, the introduction of toxic gases, or fire damage—requiring the control room to be abandoned—environmental conditions need to be considered as negative impacts to the crew's success. If any smoke or toxic gas is present in the control room, the stress decision tree evaluates to *high stress* because the plant is not responding as expected (because the HVAC system is failed). It is outside the scope of the EPRI approach to address different levels of smoke. If smoke in the control room impacts visibility such that operators will have difficulty locating the cues, all instrumentation is considered impacted, and the HFE should evaluate to 1.0. It is outside the scope of the EPRI approach to address visibility affecting cognition.

For local actions, environmental conditions could be an important influence on operator performance. Radiation, lighting, temperature, humidity, noise level, smoke, toxic gas, and weather for outside activities (e.g., having to go on a potentially snow-covered roof to reach the

atmospheric dump valve isolation valve) can be varied and far less than ideal. Fires can introduce additional environmental considerations not normally experienced in the response to internal events. These include heat, smoke, the use of water or other fire-suppression agents or chemicals, toxic gases, and different radiation exposure or contamination levels. Any or all of these may adversely impact operator actions in the locations where the actions are to be taken and along access routes. If any one of these PSFs is considered to have a negative impact, high stress is applied. If any two of these PSFs are considered poor, high stress is applied. In most of the cases described previously, there is more than one negative PSF (because the PSFs are not independent); therefore, it is essential that the feasibility of the operator action be confirmed.

During a fire, the crew's ideal travel path to the action location might be blocked by the fire, leading to a delay or inability to reach the action location. Where alternative routes are possible, the demands associated with identifying such routes and any extra time associated with using the alternative routes should be factored into the analysis. According to NUREG/CR-6850 [5], if the action is required to be performed in the same location as the fire, the action should not be credited in the fire PRA. If the local actions required a detour because of the fire location, the time for the detours is to be included in T_m. Additionally, the stress would be considered high because the accessibility for the action is limited by the fire location.

An evaluation should be performed to address the issue that any equipment necessary for the completion of hot shutdown from the remote shutdown panel is accessible and in working order such that it will not be adversely affected by the fire or its effects (e.g., heat, smoke, water, combustible products, and spurious actuation). The timeliness and success rate in reaching systems and equipment should be assessed in the demonstration for feasibility or judged conservatively to adequately adjust for the greater stress and time pressure on the operators working in the likely unfamiliar environment and ex-CR controls. If it is qualitatively assessed that at the hot shutdown panel a piece of equipment would not be in working order and that the equipment is required for success, the HEP should be set to 1.0. It is not within the scope of this method to address repairing equipment damaged by the fire.

B.8.8 Special Equipment

Because of varying environmental conditions during a fire, the crew may require the use of special equipment. These items, identified in NUREG-1852 [8] as *portable equipment*, can include keys, ladders, hoses, flashlights, clothing and dosimetry to enter high radiation areas, and, for fire, special protective clothing and SCBA gear. The accessibility of these tools needs to be checked to ensure that they can be located and accessed during a fire. If they cannot be accessed during the fire, the HEP evaluates to 1.0. It is outside the scope of the EPRI method to address locating secondary equipment if the primary pieces are not available. Furthermore, the level of familiarity and training on these special tools needs to be assessed. The familiarity with special equipment can be addressed by choices for EOCs in THERP.

The call for abandoning the MCR might also require the donning of protective gear or SCBA gear. The hindrance of the special clothing on the operators' actions needs to be accounted for. The time to don SCBA can be observed during annual SCBA training and included in T_m. For HFEs that require SCBA gear, it should be ensured that there is enough time to perform the action even when a conservative estimated time to don gear is assumed. It is assumed that operators would not need SCBA gear to make diagnoses; therefore, SCBA gear would impact execution only. It is outside the scope of this method to address cognition while wearing SCBA gear. It is also expected that the fire PRA will not model these kinds of actions.

B.8.9 Special Fitness Needs

According to NUREG/CR-6850 [5], the fire and its effects could cause the need to consider actions not previously considered under internal events or changes to the way in which previously considered actions are performed. Checks should be made to ensure that unique fitness needs, such as the following, are not introduced:

- Having to climb up or over equipment to reach a device, possibly because the fire is blocking the ideal travel path
- Needing to move and connect hoses, using an especially heavy or awkward tool
- Resulting physical demands of using SCBAs, which could impact communication

If the fire causes any of these unique fitness needs such that not all crew members could perform the required tasks, the HEP should be set to 1.0. If the operators are required to climb over equipment or move and connect awkward hoses, this would be reflected in T_m, and the stress level would be impacted by accessibility. Communication impacts would be reflected in an increased stress level.

B.8.10 Crew Communications, Staffing, and Dynamics

Crew-to-crew variability is modeled in the HCR/ORE by using the appropriate bound for sigma. For EOP actions with no fire impacts to instrumentation, the nominal sigma case can be used. For cases in which there could be crew-to-crew variability resulting from fire impacts such as confusion in procedure, instrumentation impacts, or decision making for control room abandonment, the upper bound for sigma will be used. Communication is explicitly addressed in decision tree p_cc, and additional crew can be credited for recovery in the CBDT trees if enough time is available. The HRA methodology documents the total number of people required for success; if the total number of crew required is greater than the total number available, the HEP should be set to 1.0.

B.8.10.1 Team and Crew Dynamics

Team/crew dynamics and crew characteristics are essential to understanding how and where the early responses to an event occur as well as the overall strategy for dealing with the event as it develops. In particular, the way the procedures are written and what is (or is not) emphasized in training (which may be related to an organizational or administrative influence) can cause systematic and nearly homogeneous biases and attitudes in most or all of the crews, possibly affecting overall crew performance. NUREG-1792 [6] recommends a review of team dynamics that includes the following:

- Are independent actions encouraged or discouraged among crew members? Allowing independent actions may shorten response time but could cause inappropriate actions to be unnoticed until much later in the scenario. If this scenario is identified to be modeled, this would be considered as in decision tree p_cb: failure of attention. High workload would be assumed, and no additional crew would be credited for recovery. If the HRA analyst wishes to model the recovery by a secondary person, this would be modeled by assuming that the first person failed the action and the second person would receive a recovery cue to either

check that the previous task was completed or take another action. The timeline for the second action would be based on the recovery cue. Additionally, the dependency approach outlined in Section 7 of this report could be used to assess the dependency between the actions.

- Are there common biases or "informal rules?" For example, is there a reluctance to perform certain acts, is there an overall philosophy to protect equipment or run it to destruction if necessary, or are there informal rules regarding the interpretation of procedural steps? Operator trust of the procedures is modeled in decision tree p_cg. If the operators believe in the adequacy of the procedures, the informal rules are considered negligible.
- Operator interviews are performed to identify any informal rules that may not be obvious during a procedure review. For example, if the operators receive a cue such as an annunciator and they know that this is an important annunciator, they may be allowed to set aside the EOPs and attend to the annunciator—even if the documented plant protocol is to not leave the EOPs until directed to do so in the EOPs. For this case, $T_{1/2}$ and T_{delay} would reflect the time at which the operators leave the EOPs and acknowledge the annunciator. Additionally, if the interviews confirm that all operators will be following a specific cue, extra crew can be credited as a recovery in the CBDT.
- Are periodic status checks performed by most crews so that everyone has a chance to "get on the same page" and allow for checking on what has been performed to ensure that the desired activities have taken place? This is addressed in decision tree p_cb.

  For fire HRA, the typical internal events crew dynamics may change as a result of responding to a fire and need to be reconsidered. For instance, the fire may create new or unique fire-related responsibilities that have to be handled by a crew member. If the total number of crew available is less than the total number of crew required, the HEP = 1.0. The HRA methodology provides a field for documenting both the number of crew required and the number of crew available. The use of plant status discussions by the crew may be delayed or performed less frequently, allowing less opportunity to recover from previous mistakes. This would be reflected in the timeline as well and in not applying recoveries for cognition. Such differences may be best determined by talk-throughs with operations staff as well as observing simulated responses of fire scenarios.

  For MCR abandonment actions or alternate shutdown actions, the crew will be dispersed to various alternate shutdown panels and controls, which requires additional coordination among all crew members. It must be ensured that adequate control room members are necessary to fulfill the needs of proper shutdown actions from alternate and remote shutdown panels. If not, the HEP = 1.0.

B.8.10.2 Communication

For both internal events and fire HRA control room actions, communications among crew should be verified. Typically, an established strategy for communicating in the control room will ensure that directives are not easily misunderstood. Do crew members avoid the use of double negatives? It is expected that communication will not be problematic; however, any potential problems in this area (such as having to talk while wearing special air packs and masks) should be accounted for, if they exist. Communications and their impact on cognition are modeled in decision tree p_cc, and additional crew can be credited for recovery in the CBDT trees if enough time is available.

If SCBA is required to be worn, this apparatus might interfere with clarity in communications among team members. Execution while wearing SCBA gear is reflected as an increase in stress level.

The general EPRI approach for communication is to verify that it is possible; if it is not and is required for success, the HEP = 1.0.

B.9 Example of Fire HFE Quantified Using the EPRI HRA Methodology

This section provides an example HFE modeled using the EPRI HRA methodology. This example is for an existing EOP action required for the fire HRA. In the fire scenario, the position switch is failed by the fire; therefore, the control room operators cannot open the valve from the control room and must dispatch a local operator to perform the action. The indication provides a correct reading showing that the valve is failed. In addition, the fire procedures direct the operator to locally open the valve.

Scenario 1: Locally close 8804A for high-pressure recirculation following a spurious power-operated relief valve (PORV) LOCA.

Table B-21 provides a basic event summary of Scenario 1.

Table B-21
Scenario 1 HEP summary

Analysis Method	CBDTM/HCR Combination
P(cog)	3.4e-03
P(exe)	2.5e-03
Total HEP	5.9e-03
Error factor	5

Identification and Definition

1. Initial conditions: steady state, full power

2. Initiating event: fire in Area 5A2

   a. The fire starts in the transformer and impacts targets in the plume and vertical trays adjacent to the flames

   b. PORV spuriously opens, resulting in small LOCA

3. Accident sequence (functional failures and successes):

   a. Reactor trip, turbine trip

   b. No ATWS

   c. No containment spray required

   d. AFW successful

   e. SI actuates due to open PORV

   f. Cooldown and depressurization required

   g. Switchover to recirculation required

4. Preceding operator error or success in sequence:

   a. Operators failed to detect spurious PORV opening prior to automatic SI actuation

   b. Operators controlled ECCS flow to match makeup flow with leakage rate

   c. RHR pumps tripped

   d. Cooldown and depressurization either failed or failed to be completed before RWST reaches 33%

5. Operator action success criterion:

   a. Recognize that 8804A cannot be closed from the control room due to fire damage

   b. Locally close 8804A located at 73-ft RHR access or 100 ft

6. Consequence of failure: RWST depletion

7. Additional notes: This is an internal events action but not currently modeled in PRA. It will be added to the fire PRA model.

The current screening HEP for this action is 0.1.

Related Human Interactions
Switchover to recirculation on low RWST level.

Initial Cue
Charging pump amps.
Charging injection flow.
SI pump flow if pumps are in operation.

Cue
RCS pressure decreasing would be the primary cue operators would be focused on for diagnosing a stuck-open PORV.

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. The operators tend to look at both the position switch and the monitor light boxes for diagnosis.

The cue for starting cold leg recirculation is RSWT level <33%.

Degree of Clarity of Cues and Indications
Average.

Procedures
Cognitive: ES-1.3 (Transfer to Cold Leg Recirculation).
Execution: ES-1.3 (Transfer to Cold Leg Recirculation).
Other: CP-M-10 (Fire Procedure).

Cognitive Procedure
Step: 8.g.
Instruction: Check for charging pumps (pps) amps, charging injection flow, and SI pump flow if pps are in operation.

Procedure Notes

By the time switchover to cold leg recirculation is required, the operators will also be looking at CP-M-10 (the fire procedure).

The procedure step in CP-M-10 reads as follows:

> 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 biannually on ES-1.3, but they are not specifically trained on ES-1.3 following a fire with various valve failures.

Training

Classroom, frequency: 0.5 per year.
Simulator, frequency: 0.5 per year.

Operator Interview Insights

The operators stated that it would be obvious that 8804A or B failed to close when they attempted to close it from the control room. In addition to the position switches, the valve position is also monitored on monitor light boxes. The cabling for the monitor light boxes is separate from the valve cabling.

The operators estimate that it will take 10 minutes to crank open the valve and 15 minutes to travel to the valve location.

The operators are aware that switchover to recirculation is coming and will have an operator preview E-1.3 (Step 13 of E-1, Preview EOP, E-1.3, Transfer to Cold Leg Recirculation.) During the preview, the crew anticipates that they will notice any mismatch on the valve position.

Manpower Requirements

Manpower requirements for Scenario 1 are shown in Table B-22.

Table B-22
Scenario 1 manpower requirements

Crew Members	Included	Total Available	Required for Execution
Reactor operators	Yes	2	1
Plant operators	Yes	2	1
Mechanics	Yes	2	
Electricians	Yes	2	
I&C technicians	Yes	2	
Health physics technicians	Yes	2	
Chemistry technicians	Yes	1	

Execution Performance Shaping Factors

Execution performance shaping factors for Scenario 1 are shown in Table B-23.

Table B-23
Scenario 1 execution performance shaping factors

Environment	Lighting	Normal
	Heat/humidity	Normal
	Radiation	Normal ambient
	Atmosphere	Normal
Special Requirements		
Complexity of Response	Cognitive	Complex
	Execution	Simple
Equipment Accessibility	Control room	Accessible
	73-ft RHR access	Accessible
Stress	High	
	Plant response as expected	No
	Workload	N/A
	Performance shaping factors	N/A

Performance Shaping Factor Notes
The fire location does not prevent the operators from reaching 73-ft RHR access.
In the scenario modeled, the operators are faced with a situation in which the plant has experienced a small LOCA due to a stuck-open PORV. They have failed to cool down and depressurize the reactor coolant system, and must effect switchover of suction for safety injection to sump. Also, because of the fire and the spurious opening of valves, the plant is not responding as expected. High stress is selected since operators do not perceive the plant conditions to be improving.

Timing
Timing for Scenario 1 is shown in Figure B-33.

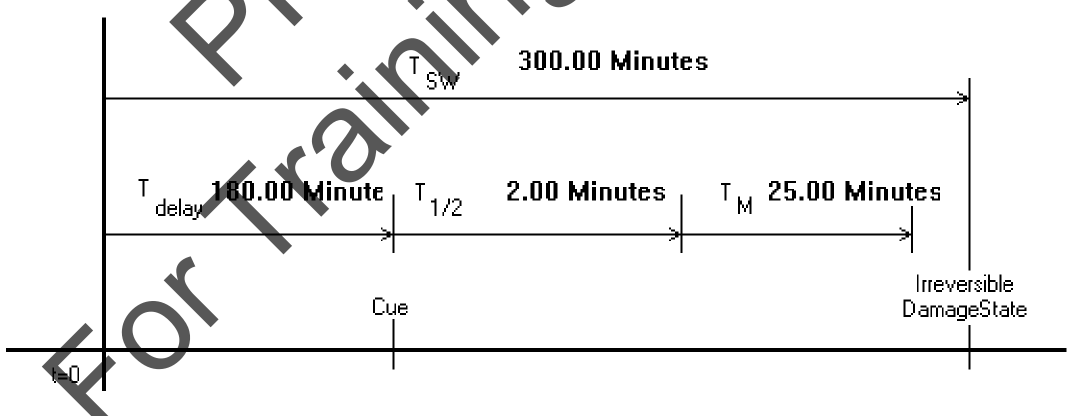


Figure B-33
Scenario 1 timing

- T_{sw} = 300 min = time to RWST depletion
- T_{delay} = 180 min = RWST <33%

- $T_{1/2}$ = 2 min = estimated time to attempt to close the control room switch and realize that the valve must be closed locally
- T_m = 25 minutes based on operator interviews

Cognitive Unrecovered CBDTM

Scenario 1 cognitive unrecovered CBDTM is shown in Table B-24.

Table B-24
Scenario 1 cognitive unrecovered

P_c Failure Mechanism	Branch	HEP
P_ca: Availability of information	a	Negative
P_cb: Failure of attention	i	Negative
P_cc: Misread/miscommunicate data	a	Negative
P_cd: Information misleading	a	Negative
P_ce: Skip a step in procedure	c	3.0e-03
P_cf: Misinterpret instruction	b	3.0e-03
P_cg: Misinterpret decision logic	j	1.0e-03
P_ch: Deliberate violation	a	Negative
Sum of P_ca through P_ch = Initial P_c =		7.0e-03

P_ca Notes
The monitor light boxes in the control room are unaffected by the fire.

P_cb Notes
Two hours into the scenario, the workload is still considered high because the operators will be working in both the fire procedures and the EOPs. The operators are required to check only the monitor light boxes located on the front panels of the control room for the valve positions.

P_cc Notes
Checking the monitor light boxes does not require the use of formal communication to complete. However, the completion of Step ES-1.3 does require formal communication.

P_cf Notes
Not all information would be available because the position indicator lights may have failed because of fire. Personnel are well trained on all EOP steps.

P_cg Notes
Failure to close valve is a result of lack of training on fire procedures.

Cognitive Recovery CBDTM

Scenario 1 cognitive recovery CBDTM is shown in Table B-25.

Table B-25
Scenario 1 cognitive recovery

	Initial HEP	Self-Review	Extra Crew	STA Review	Shift Change	ERF Review	DF	Multiply HEP by	Override Value	Final Value
P_ca	Negative	-	-	-	-	-	-	1.0e+00		
P_cb	Negative	X	-	-	-	-	-	1.0e-01		
P_cc	Negative	-	-	-	-	-	-	1.0e+00		
P_cd	Negative	-	-	-	-	-	-	1.0e+00		
P_ce	3.0e-03	-	-	-	-	-	-	1.0e+00		3.0e-03
P_cf	3.0e-03	-	-	X	-	-	-	1.0e-01		3.0e-04
P_cg	1.0e-03	-	-	X	-	-	-	1.0e-01		1.0e-04
P_ch	Negative	-	-	-	-	-	-	1.0e+00		
Sum of P_ca through P_ch = Initial P_c =										3.4e-03

Note: Due to time available, STA is credited for recovery.

Cognitive HCR/ORE

Sigma for Scenario 1 cognitive HCR/ORE is shown in Table B-26.

Table B-26
Sigma table

Plant Type	Response Type	LB	Sigma	UB
BWR	CP1	0.4	0.7	1
	CP2	0.2	0.58	0.96
	CP3	0.59	0.75	0.91
PWR	CP1	0.26	0.57	0.88
	CP2	0.07	0.38	0.69
	CP3		0.77	

Sigma: 3.8e-01
HEP: Negligible

Notes/Assumptions: The average sigma is used because this action is proceduralized in the fire procedure and in the EOPs. By the time the operators reach this action, they will have reviewed the fire procedures.

Execution Unrecovered

Scenario 1 execution unrecovered is shown in Table B-27.

Execution Recovery

Scenario 1 execution recovery is shown in Table B-28.

Table B-27
Scenario 1 execution unrecovered

Procedure: ES 1.3, Transfer to Cold Leg Recirculation		Comment				Stress Factor	Override
Step No.	Instruction/Comment	Error Type	THERP		HEP		
			Table	Item			
E-1.3 Step 4 RNO	Locally close 8804A (73-ft RHR access)					5	
	--	EOM	20-7b	4	4.3E-3		
		EOC	20-13	1	1.3E-3		
						Total Step HEP	2.8e-02
E-1.3 Step 8	Check for charging pp amps, charging injection flow, and SI pp flow if pps are in operation					5	
	--	EOM	20-7b	4	4.3E-3		
		EOC	20-11	4	3.8E-3		
						Total Step HEP	4.1e-02

Table B-28
Scenario 1 execution recovery

Critical Step No.	Recovery Step No.	Action	HEP (Crit.)	HEP (Rec.)	Dep.	Cond. HEP (Rec.)	Total for Step
E-1.3 Step 4 RNO		Locally close 8804 A (73-ft RHR access)	2.8e-02				2.5e-03
	E-1.3 Step 8	Check for charging pp amps, charging injection, and SI pp flow if pps are in operation		4.1e-02	LD	8.9e-02	
		Total Unrecovered	**2.8e-02**			**Total Recovered**	**2.5e-03**

B.10 References

1. *Operator Reliability Experiments Using Nuclear Power Plant Simulators.* EPRI, Palo Alto, CA: 1990. NP-6937, as supplemented by EPRI TR 100259 [2].
2. *An Approach to the Analysis of Operator Actions in Probabilistic Risk Assessment.* EPRI, Palo Alto, CA: 1992. TR-100259.
3. U.S. Nuclear Regulatory Commission. NUREG/CR-1278, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, (THERP), A. D. Swain and H. E. Guttman, 1983.
4. *Systematic Human Action Reliability Procedure (SHARP) Enhancement Project: SHARP 1 Methodology Report.* EPRI, Palo Alto, CA: 1992. TR-101711.
5. U.S. Nuclear Regulatory Commission. NUREG/CR-6850, EPRI 1011989, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities.* September 2005.

   Note: When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following as well:

   Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.
6. U.S. Nuclear Regulatory Commission. NUREG-1792, *Good Practices for Implementing Human Reliability Analysis (HRA)*, Sandia National Laboratories, 2005.
7. 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*, The American Society of Mechanical Engineers, New York, NY, February 2009.
8. U.S. Nuclear Regulatory Commission. NUREG-1852, *Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire*, October 2007.

APPENDIX C
DETAILED QUANTIFICATION OF FIRE HUMAN FAILURE EVENTS USING ATHEANA

C.1 Objective

This appendix provides a brief description of how to apply the NRC-developed "A Technique for Human Event Analysis," or ATHEANA human reliability analysis (HRA) method, in quantifying many of the human failure events (HFEs) identified in the fire PRA models.

Specific guidance describing the process for applying the method is presented in NUREG-1880 [1] and NUREG-1624, Rev. 1 [2]. ATHEANA is an HRA methodology specifically designed to identify, model, and quantify errors or commission (EOCs). However, this approach may be used in any instance in which a simpler HRA methodology is not valid because of the complexity of the scenario (especially those involving diagnosis or cognitive complexity that could result in multiple credible paths from which operators can choose). ATHEANA is based on reviews of operating experience in technically challenging domains (including nuclear power plants [NPPs] and others with complex technologies) combined with insights from recent advances in cognitive and behavior science. A key observation that drives the ATHEANA approach for NPPs is that "real" HFEs do not usually occur randomly or as a result of simple inadvertent behavior (such as missing a procedure step or failing to notice certain indications because they are on a back panel). Instead, HFEs in these situations occur when the operators are placed in an unfamiliar situation for which their training and procedures are inadequate or do not apply or when some other unusual set of circumstances occurs (i.e., the operators are "set up" by the operational context). In such situations, incorrect assessments are often made with regard to the status of the system being monitored or controlled, and subsequent human actions may not be beneficial or may even be detrimental.

It is likely that some fire scenarios may have complicating characteristics that match well with the types of scenarios that ATHEANA was designed to address. So, when fire scenarios and related HFEs cannot be adequately covered by the simplified fire HRA, the potential for the scenarios being particularly challenging and the need to perform an ATHEANA analysis should be carefully considered. Certainly, fire scenarios with the potential for unexpected spurious indications or equipment actuations that would be difficult to track and understand would be strong candidates for an ATHEANA analysis.

This appendix is divided into three additional subsections:

- Section C.2 summarizes the ATHEANA method that is described in more detail in NUREG-1880 [1] and NUREG-1624, Rev. 1 [2].
- Section C.3 discusses specific needs for performing fire HRA with ATHEANA. In particular, several of the ATHEANA steps summarized in Section C.2 are not required for fire HRA; others may have been performed already, at least in part.

- Section C.4 provides an illustrative example of how to apply ATHEANA in a fire HRA/probabilistic risk analysis (PRA) study.

C.2 Summary of the Method

Step-by-step guidance on how to apply ATHEANA during an internal events PRA is covered in the ATHEANA User's Guide (NUREG-1880 [1]). NUREG-1880 provides a simplified version of the multi-step analysis process covered in NUREG-1624 [2]. The ATHEANA process is presented in Figure C-1. Detailed discussion of each of these steps can be found in NUREG-1880 but is briefly summarized here. As can be seen in Figure C-1, the ATHEANA process is much more than simply a quantification process (because it entails several steps prior to quantifying HEPs). Also note that although the process presented in the figure appears to be mostly linear, in reality these nine steps can be an iterative process.

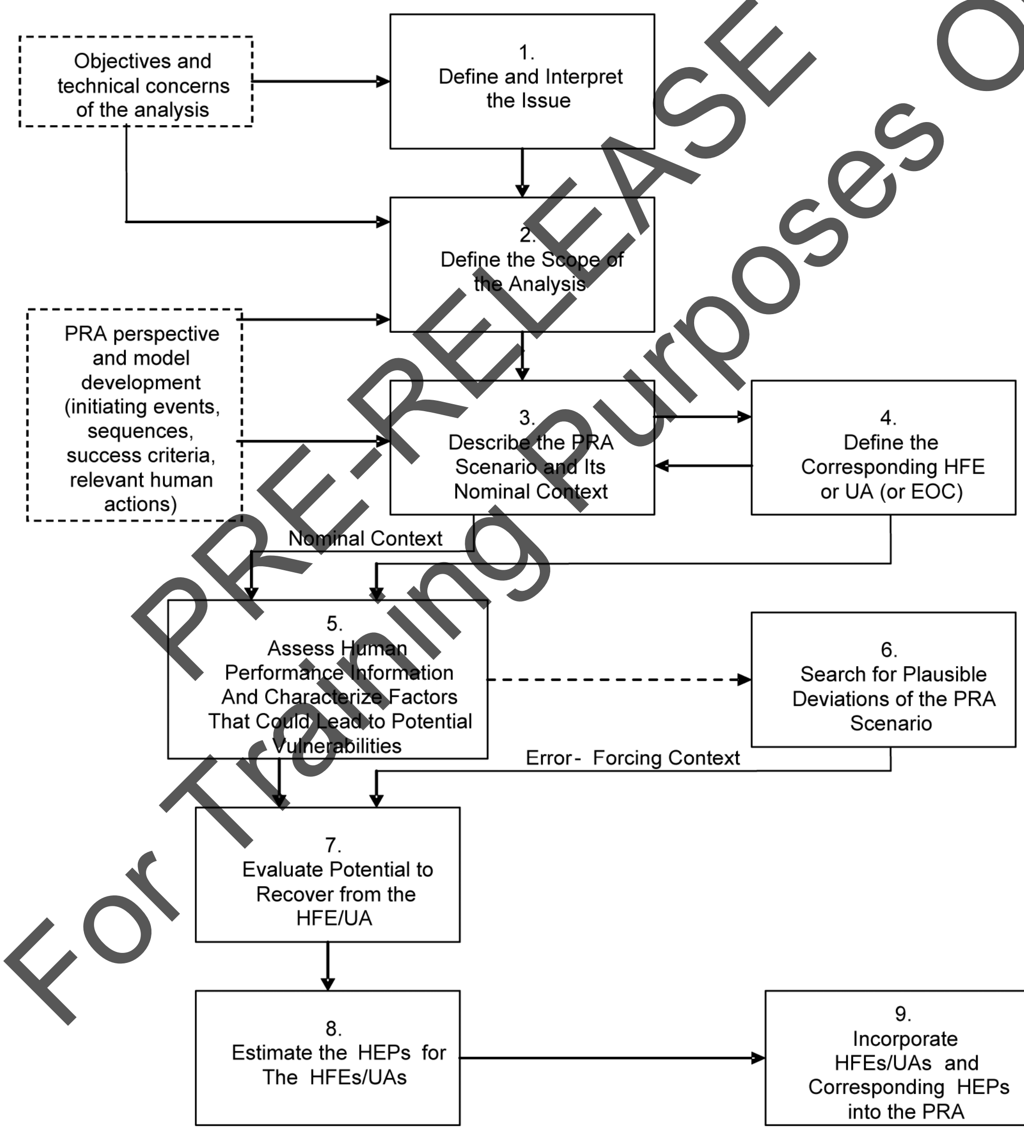


Figure C-1
Steps in the ATHEANA methodology

Appendices B, C, and D in NUREG-1624, Rev.1 also provide illustrative examples of how ATHEANA can be applied to three different types of initiating events: degradation of secondary cooling, large loss-of-coolant accident (LLOCA), and loss of service water. These appendices illustrate how ATHEANA steps can be performed and show example results for ATHEANA steps. However, because the ATHEANA quantification approach was not fully developed in NUREG-1624, Rev. 1, NUREG-1880 should be used as the analyst's principal reference for the final quantification step.

C.2.1 Steps 1 and 2: Define the Issue and Analysis Scope

Prior to beginning the analysis, the analysts need to thoroughly understand what it is they are quantifying, including the general context surrounding the HFE and success criteria. Although it is recommended that analysts review the introduction to NUREG-1880 and all of the ATHEANA steps prior to quantifying fire scenario HFEs, the identification of HFEs, their inclusion in the fire PRA models, and much of the fire context and related information needed to apply the ATHEANA quantification process will have already been defined by the overall fire PRA and identified in applying Steps 1–3 (Sections 3–5) of this report.

C.2.2 Step 3: Describe the Nominal Context

In this step, the analyst will determine and document the expected progression of the scenario, that is, the scenario that represents the most realistic description of expected plant and operator behavior for the selected issue and initiator. The description should contain elements such as the following:

- Initial plant conditions
- Sequence of events and expected timing before and following reactor trip
- Plant system and equipment response
- What the operators will see (i.e., trajectories of key plant parameters and indications)
- Key operator actions during the scenario progression

Regardless of the HRA method applied, the process of describing the scenario is universal and not unique to ATHEANA. As such, much of the information needed to put together this scenario will have already been collected as part of the qualitative analysis described in Section 4 of this report. However, it is import to note that—because this scenario description provides the bases of quantification using an expert elicitation process—it is important that the description and its related context be clear and uniformly available at an appropriate level of detail to enable the experts to visualize the scenario and assess the importance of various parts of the context as it relates to performance of the human actions of interest.

There are several data sources to draw from in compiling the base case scenario, including the final safety analysis report (FSAR), safety analyses, and simulator observations. However, in practice, the available information defining a base case is often less than ideal, and analysts must supplement information deficiencies or simply recognize them.

C.2.3 Step 4: Define the HFE

In this step, the analyst identifies the human action(s) of interest and defines a corresponding HFE and associated unsafe actions (UAs) (i.e., the specific operator actions that are taken, or not taken when needed, that make up an HFE). This step is already covered by the fire HRA methodology (see Section 3, Identification and Definition) and does not need to be repeated here; however, if appropriate, the analyst may choose to break down the given HFE into specific UAs to support HRA quantification needs.

C.2.4 Steps 5 and 6: Search for Error-Forcing Contexts

Step 5 is geared toward fully understanding how the plant conditions represented in the PRA scenario may create a challenging operational situation for the operating crew. Typically, the way to describe the impact of a challenging operational context is through the identification of driving factors, often called *performance shaping factors* (PSFs). The plant conditions and performance shaping factors together define the *error-forcing context* (EFC).

As described elsewhere in this report, a spectrum of performance influencing factors (e.g., PSFs, timing, dependencies, available staffing, informal rules, progression of the scenario) should be evaluated in order to pinpoint specific factors that could lead to a potential vulnerability or positive factors that contribute to success (typically, only a few factors are key drivers to performance). Again, much of this information may have been gathered as part of the qualitative analysis, but the search here is intended to be much more detailed than what is required for screening and/or scoping. Operators and trainers must play a role in this step. Ways to identify vulnerabilities include the following:

- Investigation of potential vulnerabilities due to biases in operator expectations (through their training and operating experience) via the review of training materials, observations of simulator exercises, and interviews of operator trainers and operators themselves
- Understanding of the base-case scenario timeline and any inherent difficulties associated with the required response
- Identification of operator-action tendencies based on the following:
  – "Standardized" responses to indications of plant conditions
  – Informal rules (see NUREG-1624, Rev. 1 for examples)
  – Evaluation of formal rules and EOPs, especially with respect to critical decision points, ambiguities or sources of confusion in procedure logic, mismatches between the timing of the actual scenario and that underlying the procedure development, and special cases such as preemptive actions

Appendices B, C, and D in NUREG-1624, Rev. 1 provide examples of the types of results that could be developed in investigating potential operator vulnerabilities. These results include procedure maps (highlighting procedure logic and transitions), timelines, and summary tables of operator vulnerability evaluations with respect to training and experience, event timing, and informal rules (e.g., "protect the pump" by turning it off when pump vibration or noise is detected).

The purpose of Step 6 is to identify scenarios that deviate[19] from the nominal scenario in such a way that the resultant HEP would be higher than would otherwise be estimated for the human response to the nominal scenario. Many deviations arise when there is a mismatch between plant behavior and the operator's expectation or procedural guidance. However, deviations are not limited to false perception in the operators' minds. In the fire analysis, often the fire itself is sufficient deviation for the analyst to stop the search. However, to the extent that there may be aleatory factors that could significantly alter the likelihood of crew success (e.g., worst-case fire scenario for a given fire area or a significant staffing shortage for a particular scenario), explicit modeling of such factors may be useful.

C.2.5 Step 7: Recovery

The possibility of recovering from UAs is considered in this step. When evaluated, *recovery* always considers both the complete EFC and the occurrence of the UA(s). The recovery analysis is scenario specific (i.e., separate analyses may need to be performed for the deviation case versus the base case), and dependencies are incorporated as part of the recovery analysis. Performance of this step is linked with quantification, and iteration between these steps is likely.

C.2.6 Step 8: Quantification

The ATHEANA methodology uses a formalized expert-opinion elicitation process to estimate the HEP rather than specific rule sets or a similar structure to convert the effects of these important influences into an HEP.

The process begins by assembling the information gathered in Steps 3–7 into narratives—or operational stories—describing how the scenario might unfold; a narrative will be developed for each context identified. The resulting operational scenario description may include the following:

1. Additional plant conditions that will need to be quantified as part of the HFE (unless the accident sequence analyst wants to revise event trees or fault trees)
2. Distinctions in the timing of plant behavior (that might need to be addressed as part of the HFE, unless logic is revised)
3. Instrument or indication issues (including failures) that will need to be reflected (for fire, these might be explicitly part of the PRA model)
4. Different possible procedure paths or response strategies that operators might rationally take
5. Reasons why operators might take different procedure paths
6. Credible recovery actions

In developing the information addressed by the last three elements, the HRA analyst is likely to need help from operational experts.

[19] A deviation scenario is a plausible deviation from the nominal conditions or plant evolutions normally assumed for the PRA sequence of interest (the nominal scenario), which might cause problems or lead to misunderstandings for the operating crews.

After these operational stories are created and agreed on by the quantification team, a ten-step process is used to perform and document the quantification:

1. Gather the experts. When applying ATHEANA to a fire context, although experts in operations and training should be included, experts who are familiar with the important relevant factors for plant personnel under fire conditions should also be included.
2. Thoroughly explain the context and the HFE/UA.
    a. This is a discussion, based on the operational story, so that all experts clearly understand what they are quantifying.
    b. Identify "driving" influencing factors to consider.
3. Elicit relevant evidence from the experts. Concrete evidence drawn from the experts' experience will help calibrate the group and avoid the "that can't happen at my plant" syndrome.
4. Guide the subsequent discussion.
5. Confirm the evidence.
6. Elicit each expert's HEP independently.
    a. Prior to eliciting values from the experts, it may be necessary to calibrate the experts against a probability scale such as the one provided in Table C-1.
    b. Note: The HEP solicited is a distribution, not merely a mean value.
7. Construct a consensus HEP.
    a. Each expert should discuss and justify the HEP estimate they provided.
    b. Openly discuss the opinions and, if necessary, refine the HFE (iterate). Discussions should continue until a consensus distribution is reached.
8. Repeat previous tasks for each HEP to be assessed.
9. Perform a "sanity check" of the estimated HEPs.
10. Document the quantification.

Details for each step of the quantification process, along with specific guidance on how to facilitate an elicitation process, control for bias, and so on, can be found in Section 3.8 and Appendix B of NUREG-1880 [1].

Table C-1
Suggested set of initial calibration points for the 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 of 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 crews/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 of 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 value is not intended to be a lower bound.

C.2.7 Step 9: Incorporate HEP into PRA

After the distributions are obtained, they can be incorporated into the PRA. If there is a range of UAs or EFCs, the distributions can be convolved and the resulting distribution used for the HFE in the PRA (see Equation C-1). There are, however, some cases in which it is more appropriate to alter the logic of the PRA to explicitly reflect the different contexts and/or UAs. These cases and their implications are discussed further in Section 3.9 of NUREG-1880 [1].

$$P(HFE \mid S) = \sum_{j} \sum_{i(j)} P(EFC_i \mid S) * P(UA_j \mid EFC_i, S)$$ **Equation C-1**

where:

S = scenario. Full operational story (might not be equivalent to PRA scenario).

UAs = unsafe actions. Different procedure paths leading to undesired outcomes and associated reasons for taking them.

EFCs = error-forcing contexts. Plant conditions, behavior, PSFs, and so on that are not explicitly modeled in PRA but needed to represent S.

The probability of each UA is conditional on *EFC* and *S*.

C.3 Application of ATHEANA to Fire HRA

Although generally the ATHEANA methodology should be applied in the same way for fire HRA as for any other HRA/PRA, some modifications are needed for the fire HRA application of ATHEANA. In particular, some of the information needed to apply ATHEANA may have been collected and analyzed previously as part of the fire HRA guidelines. Table C-2 provides a mapping of the ATHEANA process steps to the fire HRA process, including notes on material covered in the fire HRA guidance in the main body of this report.

For example, although fire-specific operator performance issues should still be considered in performing all steps, the early steps (i.e., Steps 1–4 and Step 5 to some extent) within the ATHEANA methodology will most likely be completed in following the fire HRA guidance provided in Sections 3–5 of this report. In addition, although there are overlaps between ATHEANA's Step 5 and the qualitative analysis guidance given in Section 4 of this report, it is still recommended that the analyst review the search strategies for identifying operator vulnerabilities described in Step 5 of ATHEANA to ensure that the various influencing factors identified using the guidance in this report and their potential impact on crew performance have been thoroughly considered. After applying Step 5, if potentially important aleatory factors have been identified (see NUREG-1880, Section 3.5.2.3), Section 3.6.2.2 of NUREG-1880 should also be reviewed. This section provides guidance on determining whether deviation scenarios, such as those with potentially important aleatory influences, should be carried forward to the quantification process.

When Step 5 and Step 6, if necessary, have been completed, it will be necessary to apply the final qualitative step (Step 7) within ATHEANA before continuing with quantification. In Step 7, the analyst examines the recovery potential for the HFE being analyzed in the context of each scenario documented. Upon completion of this step, the description of each scenario is extended using the information obtained in the evaluations to justify the judgment of either a high or low recovery potential. This information is then carried forward for quantification. Following the completion of the qualitative analysis, ATHEANA offers a quantification technique that uses an expert elicitation process that can take advantage of the entire knowledge base gained in performing earlier steps. Note that the team of experts should be expanded to include experts knowledgeable in important relevant factors within a fire context.

Table C-2
ATHEANA process steps

ATHEANA Process Step	Fire HRA Guideline Process Step
Steps 1 and 2: Define issue and scope of analysis.	Defined by fire PRA and its scope of analysis—no additional work needed.
Step 4: Define HFEs and UAs.	Covered* by Section 3, Identification and Definition.
Steps 3 and 5: Describe PRA scenario and assess human performance information and so on.	Some additional information needed for detailed HRA, but mostly covered by Section 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 Section 6, Recovery.
Step 8: Quantification (explicitly addresses dependencies and develops uncertainty distributions)	Different approach than scoping trees (Section 5) or the EPRI HRA Approach (Appendix B); different approach to dependency and uncertainty (Section 6).

* Note: Initial HFE identification and definition will be addressed by Section 3; however, further refinements may be required in later steps of the fire HRA process (including quantification).

C.3.1 Additional Guidance for Qualitative Analysis of Fire Scenarios Using ATHEANA

This section provides some discussion of how to specifically apply the ATHEANA HRA method when using this report. Remember, the objective or final result of the ATHEANA qualitative analysis (Steps 3 and 5–7) is a full operational scenario description, or "operational story." The resultant narratives should include accident progression and as many details as are reasonable, such that operators and trainers can "put themselves into" the scenario because, in quantification, those experts will be asked, "What would your crews do in this situation?"

To accomplish this understanding of possible operator performance in fire scenarios, the analyst must obtain, for example, an understanding of the following:

- Procedures used in fire scenarios
- Use of those procedures (e.g., in conjunction with EOPs)
- Potential fire effects and their impact on human performance
- Fire PRA scenarios with associated equipment and indication failures
- Possible crew responses to fire scenarios (both possible EOMs and EOCs)

If not already developed in performing qualitative analysis according to Section 4 (either generally or in support of another fire HRA quantification approach, such as screening or scoping), it is important to the application of ATHEANA that the following additional types of qualitative analysis are performed:

- Identification of important decision points or branching as well as other possible places in procedures where operators may make different choices
- Identification of plant-specific "informal rules" (i.e., informal operational guidance or practice) and other guidance (e.g., administrative procedures) that may supplement or, at times, slightly deviate from the relevant procedural guidance (see Table 9.13 in NUREG-1624, Rev. 1 [2] for examples)
- Development of insights from training, experience, or demonstration of fire-related operator actions (both in-control room and ex-control room), including the use of specialized equipment
- Timelines or other ways to represent the time-sequencing of events (e.g., plant behavior, equipment, and operator response) in fire scenarios

Then, for each HFE and associated fire scenario, qualitative HRA using ATHEANA should address the following (with the help of and input from operator trainers and, as needed, other experts, for example, in operations, PRA, and thermal hydraulics):

1. Identification of any factors (e.g., specific fire scenario conditions, timing of plant conditions and behavior associated with the scenario, and the availability of specific equipment—including equipment degradations) that may influence different operator decisions or actions (identified previously).
2. Identification of any tradeoffs (i.e., operators have to make impromptu choices between alternatives for which there may be both positive and negative effects) or other difficult decisions (see Table 9.15a in NUREG-1624, Rev. 1 for examples of other potential problems in "response planning") that operators may need to make.
3. Identification of potential situations in which operators may not understand the actual plant conditions (e.g., spurious indications mislead operators to take, or not take, an action) (see Table 9.15b in NUREG-1624, Rev. 1 for examples of scenario characteristics that could lead to problems in "situation assessment"; spurious indications would fall under the category of missing information).
4. Identification of different ways by which an HFE could occur (i.e., define sub-events), starting with the fire PRA scenario description, different procedural paths or choices, and the reasons for these different choices. (Note that, for each different sub-event, this analysis results in the development of the qualitative description of the EFC.)

The first item implies (and much of the discussion in Section 4 addresses) that the development of timing information is extremely important. In addition, as discussed in Section 4.6.2 (regarding timing as a PSF), it should be recognized that timing estimates (especially those related to times for operator decision making and execution) can have uncertainties. As originally conceived in NUREG-1624, Rev. 1 and NUREG-1880 [1], it is intended that ATHEANA applications explore such ranges of potential conditions and associated differences in expected operator response. Such differences can have an important impact on which HFEs

are modeled and their quantification. In particular, for the application of all fire HRA quantification methods, HRA analysts need to collect a range of crew response times in addition to the “point estimate” of an average crew. This is especially important when the required time is close to the time available.

C.3.2 Defining Base Case Versus Deviation Cases: When Is Step 6 Necessary?

For many ATHEANA applications, Step 6 (i.e., the search for deviation scenarios) is essential to the development of reasons that operators may fail. For example, the ATHEANA perspective on at-power, internal events, PRA scenarios that are well-matched to EOPs, associated operator training, and the interface of U.S. control rooms is that there is little reason to expect operators to fail. Instead, some deviations from the expected or planned-for accident scenario must occur in order create a context in which operator failure is credible.

However, some accident scenarios, such as fire events, already have characteristics that represent operationally challenging events for operators. Consequently, further deviations from the PRA-defined scenario are not needed to identify potential causes for operator failure. Appendix D in NUREG-1624, Rev. 1 (particularly Section D.6) describes a similar situation for a loss of service water event.

C.3.3 Additional Guidance for Quantitative Analysis of Fire Scenarios Using ATHEANA

After the qualitative analysis described previously has been performed, HFE quantification using ATHEANA can be performed. For HFE quantification, NUREG-1880 [1] is the best reference for analysts to use in applying ATHEANA. Because it is possible that HFE sub-events may be identified, quantification may include three major elements:

1. Quantification of the frequency of different plant or fire conditions (that would cause or influence operator understanding and/or choices)
2. Quantification of the probability of different operator understanding and/or choices (given the plant or fire conditions)
3. Quantification of the failure probability for the HFE (or HFE sub-event) given Items 1 and 2

Analysts have the choice of defining new HFEs (instead of HFE sub-events, called *unsafe actions* in NUREG-1880 and NUREG-1624, Rev. 1 [2]) or summing the HFE sub-event probabilities.

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. When 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 those given in NUREG-1880.)

C.3.4 Iterating Between Qualitative Analysis and Quantification

It should be noted that, in ATHEANA, as described in Section 4, there is likely to be some iteration between quantitative and qualitative analysis. The only concern is that each HFE (and sub-event HFEs) and associated scenario can be understood **in the same way** by all participants in the quantification process.

If the HFE being quantified is associated with an operational scenario that represents, for example, a wide range of plant conditions, the experts in the ATHEANA quantification panel may not have the same understanding of the context and its potential impact on operator performance. Different experts may focus on different plant conditions, resulting in different driving factors (or PSFs) being important to operator performance.

In ATHEANA quantification, members of the expert panel need to have the same understanding of the operational scenarios or they will be quantifying different HFEs. Therefore, 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. Following are some example indications that an HFE and its associated scenario need to be redefined:

- During quantification, 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:
  - Asks everyone to include this factor during quantification, or
  - Defines a new HFE to address this newly defined scenario

For example, uncertainties in timing estimates (see Section 4.6.2) can result in important differences in assigned HFE probabilities. Although not exactly equivalent to the "tipping points" in the scoping or EPRI HRA Approach (because they are not predefined or as easily identified), the effect in ATHEANA quantification is the same. Although not required, the ATHEANA user might find it easier to identify and separate such cases that equate to "tipping points" in timing estimates since reaching consensus among the expert panel and developing the associated distributions might be simplified.

Another resource for ATHEANA quantification in fire PRA is the strawman list of sources of modeling uncertainty found in Table 6-2. This list might be helpful in exploring "worst case" and "best case" extremes of scenarios with the expert panel, providing seeds for discussion about how timing estimates and other possible scenario conditions might vary.

Such redefinition of the HFEs and associated operational scenario descriptions should be done both for and by operational experts who are participating in the expert panel for quantification.

C.3.5 Additional Guidance for Addressing Operator Response to Spurious Indications

Because one principal reason that the ATHEANA HRA method was developed was to address EOCs that might result from operators not understanding the real accident context (including potential instrumentation failures or misleading indications), one issue for which the ATHEANA approach may be particularly helpful is in addressing operator response to spurious indications in fire PRA. ATHEANA could be used to evaluate the following:

- For EOCs, either or both the initial failure in responding to the spurious indications and the recovery of this failure
- EOCs (or EOMs) due to spurious indications

In both cases, ATHEANA's approach to investigating potential operator vulnerabilities can provide useful support in justifying the appropriate dismissal of the spurious indication as erroneous information. Typically, this investigation focuses on the potential negative impact of normal or typical operator behavior—but in the wrong context. This same investigation can look at the positive impact instead. Consequently, the ATHEANA Step 5 approach can be used to identify how operator training and experience, informal rules, and habits could help in identifying an erroneous indication.

In the scoping approach, for example, it is automatically assumed that operators will respond to spurious indications as if they are accurate. However, ATHEANA could be used to investigate the scenario in more detail, examining the possibility that the operators would not respond immediately to the spurious indication. However, it should be noted that the current fire HRA guidance for identifying such HFEs is focused principally on indications that 1) are single inputs to deciding to take an action or make a procedure transition, 2) do not require any verification of the (erroneous) indication, and c) in practice, tend to correspond to easily reversible actions consistent with operator "informal rules" for protecting plant equipment (e.g., turn off pump due to high lube oil temperature). In other words, it may be difficult to justify a HEP less than 1.0 for such spurious indications. However, there may be other HFEs that do not meet all of these criteria; investigating those initial failures might be fruitful.

To investigate the possibility of recovering from an EOC due to spurious indications, the ATHEANA analysis should include factors addressed in the scoping approach as a kind of feasibility test:

- Is there time to recover?
- Are there new cues or procedure steps for recovery?
- Are initial actions reversible?
- If initial actions are not reversible, are other relevant systems or equipment available?

Then, additional factors such as training and experience can be explored with operational experts. In such cases, the experience may not need to be fire specific.

ATHEANA can also be used to investigate other impacts of spurious indications on operator performance, such as that described in Section 4.10. In such cases, the fire scenario may not be fully described with respect to all of the spurious indications and alarms that could occur. In particular, spurious indications and alarms might be present that are unrelated to the actions required for safe shutdown but could still be a distraction or delaying factor in operator response. As discussed in Section 4.10, the resulting impact on operator response might be minimal or extreme, and it might be difficult to predict operator response in a specific fire context. For example, it might seem reasonable to expect operators to ignore spurious indications for certain secondary-side systems. However, real-world accidents have shown that operators can become focused on preexisting conditions and configurations unrelated to accident response, making such assumptions questionable. In general, ATHEANA was designed to address such complex scenarios through a combination of tools and techniques that use historical events, operational experience from the expert panel, and system-based techniques to identify ranges of plant conditions that could be operationally challenging. However, for fire events, the accident record and operational experience for response to spurious indications is **very** limited—so the abilities of ATHEANA to explore this issue are similarly limited.

C.4 Example of a Fire HFE Quantified Using ATHEANA

This section provides an illustrative example of detailed analysis for an HFE using the ATHEANA method. Figure C-1 illustrates the first nine process steps defined by ATHEANA (i.e., all but the documentation step). In this example fire scenario, a fire in the turbine room causes a station blackout (SBO). The fire causes the auxiliary feedwater (AFW) to fail and the pressurizer power-operated relief valve (PORV) to spuriously open. Following loss of both buses and emergency diesel generators (EDGs) failing to start, the operator must manually align the 115-kV (alternate power source). The operator has 90 minutes before core damage due to the stuck-open PORV.

C.4.1 Steps 1 and 2: Define the Issue and Analysis Scope

At this point in the fire PRA, the analyst has determined a need to perform a detailed analysis on a specific HFE or set of HFEs. Steps 1 and 2 of the ATHEANA process, relating to the definition of the analysis scope, are already defined by the scope of the PRA. In this example, the HFE and associated context have been defined by the fire PRA as shown in Figure C-2. The HFE is as follows: **Operator fails to manually align 115-kV alternate power following loss of both buses and EDGs fail to start**.

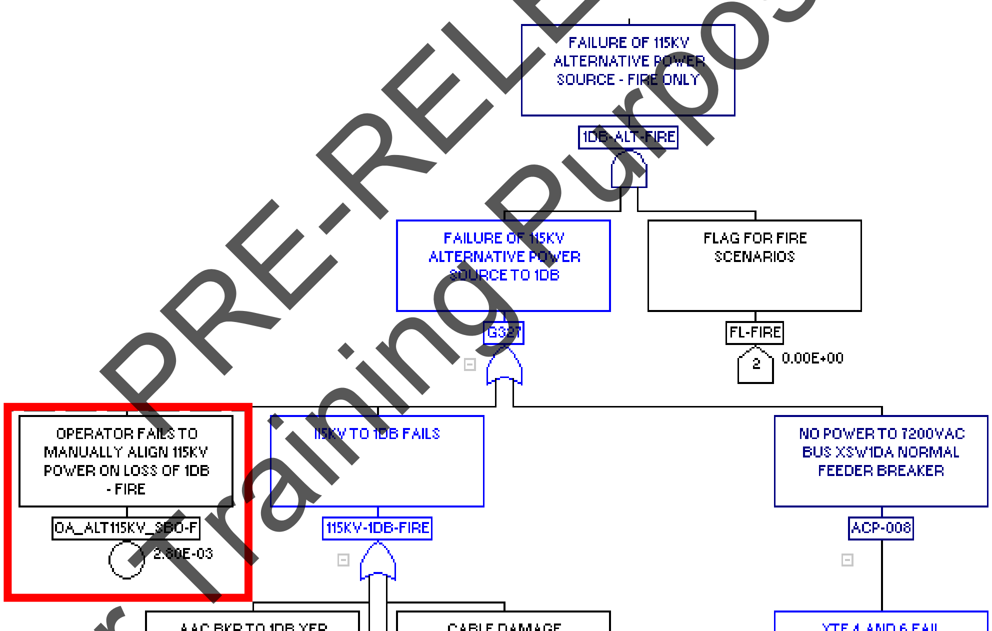


Figure C-2
HFE in failure of 115-kV alternate power source fault tree

C.4.2 Step 3: Describe the Nominal Context

After the HFE is defined, the analyst gathers plant-specific data and uses them to describe the nominal context for the scenario. Much of these data will have already been gathered as part of the qualitative analysis. The nominal context—or base case scenario—represents the most realistic description of expected plant and operator behavior for the given HFE.

After gathering the appropriate data, for this example, the accident sequence is as follows:

1. Reactor trip successful.
2. Turbine trip successful.
3. AFW failed due to the fire.
4. Pressurizer PORV spuriously opens due to the fire.
5. The main generator breaker opens, and the balance-of-plant (BOP) buses are powered through transfer switches XTF0001 (reverse) and XTF0002.
6. EDG B will start, and the Engineering Safety Features (ESF) loading sequencer will load the bus.
7. Given that the EDGs do not start (or start and trip) or if the EDG output breaker would not close, the ESF loading sequencer would still be sending a signal to trip the normal and alternate feeder breakers (for EDG protection) to the bus. This means that, to close the alternate feeder breaker (or reclose the normal feeder breaker), power must be removed from the ESF loading sequencer (ESFLS) to remove the trip-open signal.
8. Buses XSW1DA or 1DB must be energized from the alternate power source.

Note: DC power is available until the batteries deplete (~4 hours) or power is restored.

Procedurally, upon reactor trip, the operators would enter EOP 0. Step 3 of EOP 0 verifies that buses are deenergized, which takes the operators to the Station Blackout Procedure, Emergency Contingency Actions (ECA) 0.0. In Step 10 of ECA 0.0, the operators will check that buses 1DB and 1DA are energized. Again, both buses are deenergized, so the procedure will lead the operators to AOP 304: Loss of Bus with No EDG. Finally, in Steps 17 and 18 of AOP 304, the operators will find the relevant response actions for this HFE. The required operator actions include the following:

1. Shift supervisor directs the control room operator to power 1DA.
2. Reset ESFLS to clear trip signal (Step 17 of AOP 304; execution is local, skill-of-the-craft).
    a. Local plant operator, stationed at or near the main control room (MCR), gets ESFLS panel key from the MCR and proceeds to the relay room.
    b. Local plant operator dons flash gear.
    c. Local plant operator opens left cabinet (~2 ft from floor) and locally removes power from the loading sequencer.
    d. Local plant operator alerts control room operator that the trip signal is clear.
3. Close breaker in MCR (Step 18 of AOP 304; execution is in MCR and proceduralized).
    a. Control room operator will ensure that Bus 1DA XFER INIT switch is in OFF position.
    b. Close Bus 1DA ALT FEED breaker.
    c. Verify that Bus 1DA potential lights are energized.

The procedures are clear and have checklist provisions; the relevant excerpt of AOP 304 is shown in Figure C-3.

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 <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. ☐	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. ☐

Figure C-3
Steps 17 and 18 in AOP 304

Nominal Conditions

Given the location of the fire and the layout of the plant, the relay room is accessible, and there is no degraded environment (e.g., no smoke) in the relay room or en route to it. Given a SBO event, lighting will be significantly reduced (i.e., flashlights and/or emergency lighting). Training is performed in these conditions. The crew is trained annually on both non-fire SBOs and the fire procedures. All other factors are average.

Working Parallel Procedures: Timing and Staffing

In this plant, fire procedures are performed in parallel with the EOPs. Because of potential coordination issues, the interaction of the two procedures has been carefully examined, and an integrated timetable created (see Table C-3). The timing presented in the table is based on a combination of job performance measure (JPM) timing requirements, simulator observations for non-fire SBO scenarios, and a talk-through with multiple operators to determine how the nominal timings would be adjusted in a fire scenario.

Table C-3
Integrated scenario timeline

Time	Event	Comment
T = 0 min	Fire and reactor trip.	
T = 0 min	Control room dispatches fire brigade to fight the fire; immediate memorized actions (Steps 1–3 of EOP 0) performed.	Fire brigade composed of three local plant operators.
T = 3 min	EOP 3, Step 3 indicates SBO. Procedure transition brief held by shift supervisor (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 Procedure (FP).
T = 5 min	OPER1 begins ECA 0.0.	
T = 7 min	Step 4 of ECA 0.0: dispatch local plant operator to investigate failure of AFW.	Assume that this local plant operator will be busy restoring AFW and not available to assist in additional actions.
T = 10 min	STA arrives.	Begins monitoring critical safety functions.
T = 15 min	OPER1 reaches Step 10 of ECA 0.0; notifies SS that they need to transition to AOP 304.	By this time, OPER2 has finished reading through FP. **Note:** Based on simulator observation, in a non-fire SBO, this step is reached in 10 minutes; an additional 5 minutes was added here to account for the delay due to the initial coordination.
T = 15 min	SS briefs control room staff on the AOP coordination with the FPs.	Seven contingent time-critical actions (listed in the first hour) in FP; two are necessary. Confirmed: FP actions will not interfere with AOP actions; sufficient personnel available to do both in parallel. Late actions (>4 hours) are postponed until SBO is recovered.
T = 20 min	OPER1 begins AOP 304; OPER2 begins directing FP actions.	OPER2 dispatches one local plant operator to perform FP actions.
T = 35 min	OPER1 arrives at Step 17 of AOP 304 (locally remove power from ESFLS).	Cue for action. Because a majority of the steps in AOP 304 are checking indicators, based on operator interviews it would take <1 minute per procedural step (including performing necessary location actions) to get to Step 17.

Table C-3
Integrated scenario timeline (continued)

Time	Event	Comment
T = 37 min	OPER1 dispatches local operator to remove power from ESFLS.	Two minutes were allotted for diagnosis (reading Step 17) and receiving approval from the SS to proceed with the action.
T = 57 min	Action successfully completed (end of Step 18).	The action to locally remove power from the ESFLS is trained on using JPM 12654: Align ALT Feed Breaker, which has a 15-minute time requirement; this has been verified by observations of the JPM. The timing starts when the operator is given the instructions to perform this action, includes donning appropriate gear, and ends when the MCR action had been completed (end of Step 18). For this fire scenario, an additional 5 minutes was added, based on a walkdown, to account for the fact that in a fire scenario the local plant operator must walk back to the MCR to report that Step 17 has been completed. Radios are not available during a SBO in this plant, and cable tracings were not performed for the phone lines and so cannot be credited.
T = 60 min	Fire is extinguished.	Determined from detailed fire modeling, accounting for location and available fuel sources.
T = 90 min	Core damage occurs if action not performed.	Determined from thermal-hydraulic run for loss of AFW and SBO with one primary PORV stuck open.

Considering that the operating crew will be in parallel procedures, staffing for this HFE was also examined during the talk-through and determined to be sufficient to perform the necessary actions. Other factors such as training and familiarity with using parallel procedures for both board operators and shift supervisors were considered. Table C-4 provides a summary of the staffing utilization during this scenario.

Table C-4
Staffing utilization breakdown

Crew Member	Total Available Before Fire	Number Assisting with Fire*	Number 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 the fire brigade and staff occupied with FPs or otherwise occupied due to the fire.

**Two is the minimum staffing requirement; during the day, there are usually three control room operators available.

C.4.3 Step 4: Define HFE and Unsafe Actions

After the nominal scenario is described, the analyst examines the HFE in the context of the nominal case and breaks it down into its failure mechanisms or UAs. This is Step 4 of Figure C-1. There are three primary UAs (depicted in Figure C-4):

1. Control room action: fail to initiate manual alignment
2. Local operator action: fail to locally remove power from ESFLS
3. Control room action: fail to close breaker in MCR (failure to properly align alternate power)

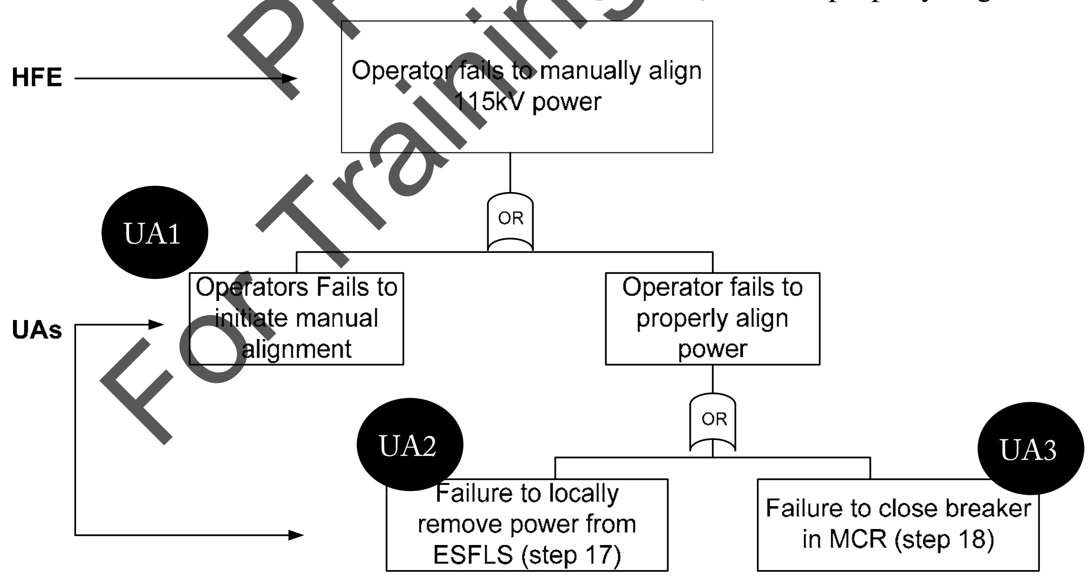


Figure C-4
Breakdown of HFE into UAs

C.4.3.1 UA1: Failure to Initiate Manual Alignment

The first failure mode would be failure to initiate manual alignment. Given the nature of the action, the clarity of the procedures (including check-off provisions), and the directly relevant training (JPM), it is unlikely that the crew will skip either Step 17 or Step 18. If they did skip either step, given the long time available for recovery (they have 33 minutes to initiate manual alignment and still have time to complete the step before core damage), this omission is unlikely to go unrecovered in the nominal scenario. However, it is possible for the fire scenario to present sufficient distractions (and other factors elongating the timeline) such that the crew could fail to initiate the action in time.

C.4.3.2 UA2: Failure to Locally Remove Power from ESFLS

After the control room operator initiates manual alignment (dispatches the local operator), the local operator can fail to remove power from the ESFLS. This is a well-proceduralized, skill-of-the-craft action that requires no diagnosis. This action is also a JPM, so it is trained on. In this case, the only credible mode of failure is an EOC (e.g., removes power from the wrong component or opens the wrong switch). If this happens, there is no local feedback, but the MCR will have clear indications that the ESFLS signal has not been cleared. Because of the lack of reliable remote communications due to the combination of fire (no telephone lines credited) and SBO (limited radio communication), no immediate feedback is available. The local operator will need to travel to the MCR (~5 minutes) to find out an error had been made and then go back and perform the action again (another 20 minutes). This additional 25 minutes brings the timeline from 57 minutes to 82 minutes, leaving 8 minutes before core damage. Therefore, there is sufficient time to recover from this action, but there is time for only one recovery opportunity.

C.4.3.3 UA3: Failure to Close Breaker in MCR

The final opportunity for failure in this sequence is failure of the control room operator to close the breaker in the MCR and align the alternate power (Step 18 of AOP 304). This is a MCR action with immediate feedback (plant power restored). The control panel layout is such that an EOC is not likely. There are good cues and a long timeframe (33 minutes) for recovery. Given the high potential for recovery, this UA is not considered for further analysis.

C.4.4 Steps 5–7: Search for Vulnerabilities, Scenario Variations, and Recovery Potential

Steps 5–7 in the ATHEANA process (Figure C-1) are iterative in nature and are aimed at creating a set of plausible operational stories, or variations on the nominal scenario, that can be used in quantification. The key to these steps is to understand whether there are any contexts that could lead to crew variability or 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. These steps are as follows:

- Step 5: Identify potential vulnerabilities
- Step 6: Search for plausible scenario variations (often not needed)
- Step 7: Evaluate potential to recover

At this point in the analysis, the team will need to expand the qualitative analysis beyond the initial effort. Operators and trainers must play a role in this part of the process either directly or through question-and-answer sessions or observation of simulator exercises (with relevant scenarios, if possible). Any assumptions should be verified against plant performance.

For this example, the analysis team iterated through these steps and found the following driving factors relevant to this scenario; recovery will be addressed as part of Step 8:

- **Training:** Operators trained on procedures, including applicable alternative actions. Non-fire SBO scenarios are common in training and "Align ALT Feed Breaker" is a JPM that is trained on biannually. Operators have annual training on fire procedures. However, they are trained on SBO as crew, not as single operators. Fire procedure training does not include performing 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 because they will be in the fire procedures. 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; the shift supervisor is a key decision point at several places in the procedures.
- **Communications:** Communication lines impacted by SBO (no radios) and landlines potentially impacted by fire (no cable tracing). The scenario timeline should be 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). These are not explicitly accounted for in the timeline.
  - Generally, local plant operators have to travel back to the MCR to report.
- **Stress due to fire:** Some stress due to ongoing fire and related distractions.
- **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 that do not perform well working on procedures in parallel.
  - Shift supervisors who are not experienced in coordinating the use of EOPs and fire procedures in parallel, especially being cognizant of operational priorities that are present in both procedure sets.
- **Special requirements:** Operators will need the key to access the relay room; all doors locked on loss of power. Not all operators have all keys.

C.4.5 Step 8: Quantification

Quantification using the ATHEANA process is a structured, expert-elicitation method with six steps:

1. Discuss HFE and possible influences and contexts using a factor "checklist" as an aid.
2. Identify "driving" influencing factors and therefore the most important contexts to consider (e.g., the operational story).
3. Compare these contexts to other familiar contexts; each expert independently provides the initial probability distribution for the HEP based on a common calibration scale.
4. Each expert discusses and justifies the HEP they provided.
5. Openly discuss opinions and refine the HFE, associated contexts, and/or HEPs (if needed); each expert independently provides a HEP (may be the same as the initial judgment or may be modified).
6. Arrive at a consensus HEP for use in the PRA.

Previously, the analysts searched for potential vulnerabilities and scenario variations associated with this HFE. Now is the time to apply these vulnerabilities to each UA identified in Step 4. In this case, each UA will be examined independently. **Note:** An unsafe action may have multiple operational stories if multiple credible contexts (EFCs) need to be examined separately.

Prior to quantification, the experts were calibrated using the scale in Table C-1. The experts were also informed that although 1E-03 was the bottom of the calibration scale, it does not impose a lower bound on their estimations.

C.4.5.1 UA1: Failure to Initiate Manual Alignment

As discussed previously, the only credible failure mechanism for the crew to fail to initiate manual alignment is for the crew to be sufficiently delayed or distracted such that they miss the timeframe for action. In this case, the crew has 33 minutes to initiate the action and still have time available to carry out the action prior to core damage. Plausible variations explored during discussion with the plant and HRA experts include the following:

- Crew variations, such as these two extremes in possible timing outcomes:
  - A 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 relies on one another. 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 performed in parallel, depending heavily on the shift supervisor for coordination, or
  - An aggressive crew, good at planning ahead and working fairly autonomously but coordinating when needed. Efficient at parallel procedures.
- Variations in shift supervisor experience and command and control style:
  - SS's first actual fire and, because it is fairly large, SS becomes very focused on the fire and less cognizant of the timeline or becomes a bottleneck for key decisions.

  - SS is calm under stress and has no problem coordinating the two procedures. The team is working at a fairly fast pace and multitasking well (e.g., dealing with distractions) but working at the top of their capacity.
- Other factors:
  - Weak team members (i.e., OPER1 is struggling to keep pace with the rest of the team). There might be a third control room operator available to look at boards and help with EOPs and/or FPs.
  - Delays in previous steps because of a combination of radio unavailability and operators having to "hunt down" appropriate keys due to change in security configuration for SBO.
  - Fairly significant fire (lasting 60 minutes), so there may be many unaccounted for distractions (e.g., failed indicators and/or spurious indicators not directly relevant to this HFE but that may take time and attention away from operators).
  - End-of-shift fatigue.

After exploring these factors, the driving factors were split into two categories: those that extend the timeline and those that affect performance. For those factors that extend the timeline, the experts were polled to determine the minimum and maximum timing variation that could be expected due to these combined factors. The extended timeline factors include slow crews, minimum staffing, excessive travel time for local actions, fire distractions, and SS as a funnel point. The experts estimated minor variations on the order of 10–15 additional minutes to get to the critical procedure step and 5–10 additional minutes to perform critical procedure steps. With this additional time factored in, the time for recovery could be reduced to as little as 8 minutes. This, however, does not jeopardize the timeline for the actions themselves.

Note: Because such a large timeframe was available for this action, this rough approach at timing analysis was determined to be adequate for quantification. If there was less time margin, the experts could choose to break this UA into two different contexts—one with worst-case timing and one with nominal timing—and then combine the HEPs using a weighting based on the likelihood of the given context (see Equation C-2).

$$P(UA_1 \mid S) = \sum_i P(UA_1 \mid EFC_i, S)$$ **Equation C-2**

Other driving factors the operators considered in producing their estimates include a range of experience levels, a mismatch between training (heavy interaction as crew) and reality (relatively autonomous), reduced cognizance of timeline due to distractions, and stress due to fire.

Considering these discussions, the (in this case, hypothetical) experts were led in a structured elicitation process (following the guidance provided in NUREG-1880 [1]) and produced the estimates in Table C-5. Each expert then gave a justification for the HEP they provided and, after brief discussion (because, in this case, the experts were similar in their initial responses with similar justification), a consensus distribution was agreed to.

Table C-5
Probability distribution for UA1 (failure to initiate manual alignment)

Analyst	Percentiles						
	1st	10th	25th	50th	75th	90th	99th
Operator	0.00001	0.0001	0.0007	0.001	0.005	0.007	0.01
Trainer	0.0001	0.0003	0.001	0.005	0.007	0.03	0.07
HRA analyst	0.00001	0.00005	0.0007	0.003	0.005	0.01	0.05
Consensus	**1E-04**	**1E-04**	**1E-03**	**3E-03**	**5E-03**	**1E-02**	**5E-02**

The final step was to "sanity check" the final distribution. In this case, the distribution passes the sanity check:

- Holistically, on average, the action was determined to be "extremely unlikely" because actions are well trained, proceduralized, have a long timeline and a high potential for recovery, and cues are clear—creating little potential for confusion or misdirection.
- 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 of the distribution adequately account for the effectiveness of crew collaboration and the specifics of timing.

C.4.5.2 UA2: Failure to Locally Remove Power from ESFLS

This is a local action that is proceduralized/skill-of-the-craft. A long timeframe is available for the action (53 minutes available for an action that takes only 20 minutes). There is sufficient training on the action because it is a JPM. However, training on this action is done in a non-fire SBO scenario only. In addition, the JPM timing is based on nominal conditions and accounts for the availability of many local plant operators to help with the procedure. With only two local plant operators available for the EOP/AOP in this scenario (four are assisting with the fire and one is attempting to restore AFW), the operator in question may be fatigued from rushing around and performing the higher workload. Given the fast pace and general stress, the local plant operator may feel rushed and open the wrong switch. An EOM is not considered credible for this scenario.

If the operator performs an EOC, recovery is possible. There are clear indications in the MCR that the ESFLS signal has not been cleared. However, it takes the local operator 5 minutes to get from the relay room to the MCR, where the operator would be told of the problem. Upon arrival

at the MCR, the local operator will be immediately re-dispatched to perform the local action. To perform the action, then, it takes an additional 20 minutes to perform the local action again, report to the MCR, and have the control room operator perform Step 18 to complete the alignment.

As in UA1, there may also be some variation in timing due to the fire scenario, reducing the time available for recovery. However, at the point at which recovery would be necessary, the fire will have already been extinguished—this would be the first priority for the crew.

There are 33 minutes available for recovery; diagnosis and execution of the recovery actions take only 25 minutes. There is sufficient time to recover.

The plant layout was examined in closer detail, and the experts concluded that the contribution due to an EOC was considered negligible (~1E-4), even discounting recovery of the local action.

C.4.6 Step 9: Incorporate HEP into PRA

After the individual HEPs are calculated for each UA, they can be combined into one distribution using Equation C-1. In this case, however, our HFE simplifies to one UA with one context, as shown in Figure C-5.

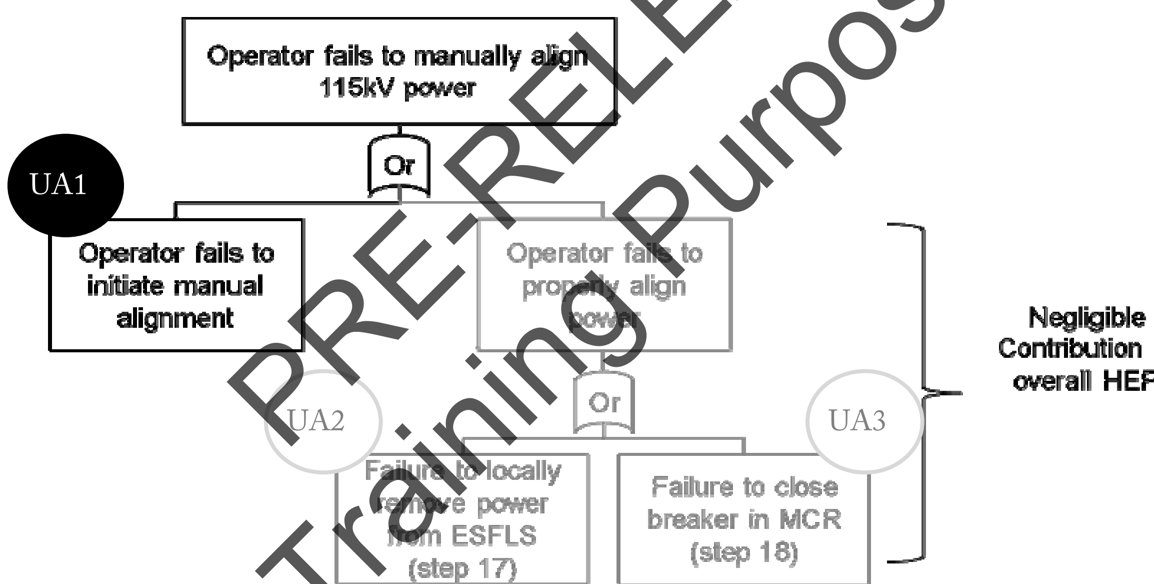


Figure C-5
Summary of HFE Logic

Therefore, for this HFE—Operator fails to manually align 115-kV alternate power following loss of both buses and EDGs fail to start—the HEP distribution is simply the same distribution as that for UA1, as shown in Table C-6.

Table C-6
Final probability distribution for HFE: Failure to manually align alternate power source

Percentiles						
1st	10th	25th	50th	75th	90th	99th
1E-04	1E-04	1E-03	3E-03	5E-03	1E-02	5E-02

Depending on the PRA needs, the entire consensus histogram can be inputted to the PRA, or a mean value may need to be developed using a software tool. NUREG-1880 provides guidance and cautions on the development of mean values from discrete distributions.

C.5 References

1. U.S. Nuclear Regulatory Commission. NUREG-1880, ATHEANA User's Guide, June 2007.
2. U.S. Nuclear Regulatory Commission. NUREG-1624, Revision 1, Technical Basis for Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA), May 2000.

APPENDIX D
ASME/ANS PRA STANDARD AND THE FIRE HRA GUIDANCE

This appendix discusses the relationship between the fire HRA guidance in this report and the high-level and supporting requirements contained in the 2009 version of the ASME/ANS PRA Standard [1]. The intent of examining the relationship between these documents is twofold:

- To ensure that relevant technical issues as defined by the PRA Standard were considered in the development of this guidance
- To examine how the fire HRA guidance provided herein maps to the PRA Standard supporting requirements and their variations by capability category to ensure that the guidance can meet the capability category desired by the user

The intent of this section is to offer a roadmap for users of these guidelines to perform an assessment of their own fire HRA against the PRA Standard requirements, not only for the HRA areas of the PRA Standard but also for other elements (such as accident sequence analysis [AS] or quantification [QU]) that interface with and provide supporting requirements for the fire HRA.

Tables D-1 and D-2 correlate the ASME/ANS PRA Standard requirements to the corresponding fire HRA guidelines section where guidance applicable to that requirement can be found. The PRA Standard requirements that differ by Capability Category are indicated with a category designation before the description, such as *Cat II* for Capability Category II. Groupings such as Cat I-II indicate that the PRA Standard requirement covers both Capability Categories I and II. Where no category designation is shown, the PRA Standard requirement is the same for Capability Categories I, II, and III.

The Capability Category gradations generally correlate to the level of specificity to the plant being studied and the level of detail of the analysis. Based on public review comments, these guidelines have been modified to reflect that meeting Capability Category III is not the intended goal of the fire HRA. However, because fire HRA depends heavily on the evaluation of plant-specific features to evaluate the performance shaping factors that influence the assessment of feasibility and the calculation of an HEP, it may be necessary to go into greater detail for those unique plant-specific design elements influencing the analysis to ensure that they are properly reflected in the results.

Table D-1 contains the basis set of internal events HRA requirements from Part 2 of the PRA Standard, which must also be met by the fire HRA; Table D-2 lists the fire HRA-specific requirements from Part 4 of the PRA Standard.

Note: The wording provided in Tables D-1 and D-2 summarizes but does not exactly replicate the PRA Standard; users of these guidelines should consult the PRA Standard itself for the exact phrasing of the requirements.

Table D-1
Part 2 ASME/ANS PRA Standard requirements for internal events HRA versus EPRI/NRC-RES Fire HRA Guidelines

ASME/ANS RA-S-2009 Requirements: Internal Events PRA [1]		Relevant Fire HRA Guidelines Section(s)
HRA Requirements		
HR-A	Systematically identify calibration, test, inspection, and maintenance (pre-initiator) activities that may impact the availability of equipment necessary to perform system functions.	Pre-initiating events HRA is not applicable to fire PRA (see Section 1.3).
HR-B	Screen pre-initiator activities from inclusion in model based on assessment of plant-specific operational practices.	
HR-C	Define HFEs that represent the pre-initiator human failure impact as an unavailability at the appropriate level (function, system, train, or component).	
HR-D	Systematically identify pre-initiator HFE probabilities based on plant-specific and activity-specific influences on human performance.	
HR-E1	Identify key human actions by reviewing (a) procedures and other relevant procedures (e.g., EOPs, AOPs, and annunciator response procedures) in the context of the accident scenarios and (b) system operation to understand how the system(s) functions and the system-human interfaces.	Section 3.2, Internal Events Operator Actions. Section 3.3, Fire Response Actions.
HR-E2	Identify actions used to initiate core damage mitigating systems and performed by control room staff to diagnose and recover a failed system, function, or component.	
HR-E3	Cat II and III: Conduct walk-throughs/talk-throughs with operations and training to verify that actions are consistent with actual plant operations and procedural practices.	Section 4.2, Information Collection. Section 4.5, HRA Narrative. Section 4.6.1, Cues and Indications. Section 4.6.3, Procedures and Training.
HR-E4	Cat II and III: Use simulator exercises and talk-throughs with operators to validate response modeling.	Section 4.2, Information Collection. Section 4.5, HRA Narrative.

Table D-1
Part 2 ASME/ANS PRA Standard requirements for internal events HRA versus EPRI/NRC-RES Fire HRA Guidelines (continued)

ASME/ANS RA-S-2009 Requirements: Internal Events PRA [1]		Relevant Fire HRA Guidelines Section(s)
HRA Requirements		
HR-F1	Cat I and II: Include and modify HFEs in PRA model as necessary to represent the impact of human failures at function, system, train, or component level as appropriate, **grouping responses into one HFE if the impact is similar or can be conservatively bounded.** Cat III: Define HFEs that represent the human failure impact at function, system, train, or component level as appropriate.	Section 3, Identifying and Defining HFEs, and Section 4, Qualitative Analysis.
HR-F2	Cat II: Complete HFE definition via accident sequence–specific cues, timing, procedures, and **train-level** tasks required to achieve the response goal. Cat III: Complete HFE definition via accident sequence–specific cues, timing, procedures, and **specific detailed tasks at individual component level (e.g., pumps or valves)** required to achieve the goal of the response.	Section 4.5, HRA Narrative.
HR-G1	Cat II: Perform detailed analysis for risk-significant HFEs, and use screening values for non-significant HFEs. Cat III: Perform detailed analysis for the estimation of human failure basic events.	Screening: Section 5.1, Screening Fire HRA Quantification (for non-risk-significant HFEs). Scoping: Section 5.2, Scoping Fire HRA Quantification (for non-risk-significant HFEs). Detailed Analysis: Appendices B and C (for both risk-significant and non-risk-significant HFEs).
HR-G2	Address cognition as well as execution errors in HEP estimation.	Scoping quantification (Section 5.2), the EPRI approach (Appendix B), and ATHEANA (Appendix C) all address cognition as well as execution.
HR-G3	Cat II and III: Address plant- and scenario-specific cues, timing, procedures, and other PSFs for HEP estimation.	Section 4.6, Performance Shaping Factors (PSFs). Section 4.5, HFE Narrative.

Table D-1
Part 2 ASME/ANS PRA Standard requirements for internal events HRA versus EPRI/NRC-RES Fire HRA Guidelines (continued)

ASME/ANS RA-S-2009 Requirements: Internal Events PRA [1]		Relevant Fire HRA Guidelines Section(s)
HRA Requirements		
HR-G4	Cat II: Use appropriate realistic generic T-H analyses or simulation from similar plants as basis for time available for operator actions. Cat III: Base time available for operator actions on plant-specific T-H analyses or simulations.	Section 4.2, Information Collection. Section 4.3.4.1, Sufficient Time for Feasibility Analysis. Section 4.5.3, Timing Information to Develop HFE Narrative. Section 4.6.2, Timing as a PSF. Scoping and detailed quantification both consider plant-specific T-H analysis.
HR-G5	Cat II: For significant HFEs, base time required for actions on walk-throughs/talk-throughs of procedures or simulator observations. Cat III: Base time required for actions on walk-throughs/talk-throughs of procedures or simulator observations (for all, not just for significant HFEs).	
HR-G6	Review post-initiator HEPs to ensure consistency with each other and reasonableness considering contextual issues.	Section 7, Documentation.
HR-G7	Evaluate degree of dependence of post-initiators, and calculate a joint HEP accordingly that reflects the dependence given procedures and other plant-specific factors (e.g., time required for actions versus time available and availability of personnel and common instruments).	Section 6.2, Dependency Analysis.
HR-G8	Assess uncertainty and provide mean HEP value.	Section 6.3, Uncertainty Analysis.
HR-H1	Cat II: Include recovery actions to restore equipment as needed to provide a **more realistic** evaluation of **significant** accident sequences. Cat III: Include recovery actions to restore equipment to provide a realistic evaluation of accident sequences.	Section 6.1, Recovery Analysis.
HR-H2	Credit recovery actions if procedures exist and training on them was provided or justification is made for why these are not necessary, cues alert operator to recovery action, PSFs addressed, and sufficient manpower is present.	

Table D-1
Part 2 ASME/ANS PRA Standard requirements for internal events HRA versus EPRI/NRC-RES Fire HRA Guidelines (continued)

ASME/ANS RA-S-2009 Requirements: Internal Events PRA [1]		Relevant Fire HRA Guidelines Section(s)
HRA Requirements		
HR-H3	Account for any dependencies between recovery HFE and other HFEs in sequence, scenario, or cutset where recovery is applied.	Section 6.2, Dependency Analysis.
HR-I1	Document fire HRA to facilitate applications, upgrades, and peer review.	Section 7, Documentation.
HR-I2	Document processes used to identify, characterize, and quantify pre-initiator, post-initiator, and recovery actions considered in the PRA, including the inputs, methods, and results.	
HR-I3	Document sources of model uncertainty and related assumptions (as identified in QU-E1 and QU-E2).	Section 7, Documentation. Section 2.4, Assumptions. Section 6.3, Uncertainty.
Other Requirements		
AS-A1	Explicitly model in accident sequence analysis the appropriate combinations of system responses and operator actions that affect key safety functions for each modeled initiating event.	Section 4.5, HRA Narrative.
AS-A4	For each modeled initiating event (in accordance with SR SC-A3), identify necessary operator actions to achieve the defined success criteria (see Notes 1 and 2).	Section 3.2, Internal Events Operator Actions, and Section 4.5, HRA Narrative. ATHEANA, Appendix C.2, Identifying and Defining HFEs, and C.5, Quantification.
AS-A6	Order the events sequentially according to the response of the systems and operator actions according to the accident progression event timing. Where not practical, provide the rationale used for the ordering.	Section 4.5, HRA Narrative.
AS-A9	Cat II: For accident sequence progression parameters (particularly timing for HRA), use realistic applicable T-H analyses from similar plants. Cat III: Use plant-specific TH analyses.	See HR-G4.

Table D-1
Part 2 ASME/ANS PRA Standard requirements for internal events HRA versus EPRI/NRC-RES Fire HRA Guidelines (continued)

ASME/ANS RA-S-2009 Requirements: Internal Events PRA [1]		Relevant Fire HRA Guidelines Section(s)
Other Requirements		
AS-B2	Identify the dependence of modeled mitigating systems on the success or failure of preceding systems, functions, and human actions. Include impact on accident progression, either in the accident sequence models or system models.	Section 2.3, Relationship to Other Fire PRA Tasks. Section 3.4, HFEs Corresponding to Undesired Operator Responses to Spurious Actuation.
SC-A Note 2	For accident sequences, supporting requirements AS-A2, SC-A3 (SC-A4, if applicable), AS-A3, and AS-A4 are intended to be used together to capture the specification of the set of systems and human actions necessary to meet the key safety function success criteria.	See individual AS SRs cited.
SC-A3	Specify success criteria for key safety functions identified for each initiating event that is modeled.	See AS-A4.
QU-E1	Identify model uncertainty sources.	Section 6.3, Uncertainty Analysis.
QU-E2	Identify assumptions made in the PRA model development.	Section 2.4, General Assumptions.
QU-E3	Estimate CDF results uncertainty interval and intervals associated with parameter uncertainties (HR-D6 and HR-G8), including state-of-knowledge correlation.	See HR-D and HR-G8.
QU-C2	Address dependencies.	Section 6.2, Dependency Analysis

Table D-2
Part 4 ASME/ANS PRA Standard requirements for Fire HRA versus EPRI/NRC-RES Fire HRA Guidelines

ASME/ANS RA-S-2009 Requirements: Fire PRA [1]		Relevant Fire HRA Guidelines Section(s)
HRA Requirements		
HRA-A1	Determine whether each safe shutdown action carried over from the internal events PRA remains relevant and valid in fire PRA context, consistent with internal events elements ES, PRM, and HR-E, or establish a defined basis to support a claim of non-applicability of any of the HR-E requirements.	Section 3.2, Internal Events Operator Actions. Section 3.6, HRA/PRA Modeling.
HRA-A2	Identify new fire-specific safe shutdown actions consistent with IE elements ES, PRM, and HLR-HR-E.	Section 2.4, General Assumptions. Section 3.3, Fire Response Actions.
HRA-A3	Cat II: Identify new undesired operator actions associated with **single instrument** failure-caused spurious indications (see ES-C2) (e.g., due to verbatim compliance with the instruction in an alarm response procedure, when separate confirmation is not available or required). Cat III: Identify new undesired operator actions associated with spurious indications resulting from failure of **up to and including two instruments at a time** (e.g., due to verbatim compliance with the instruction in an alarm response procedure, when separate confirmation is not available or required).	Section 3.4, HFEs Corresponding to Undesired Operator Responses to Spurious Actuation. Section 4.6.1, Cues and Indications.
HRA-A4	Cat II and III: Talk through procedures and event sequences with plant personnel to ensure that operator actions modeled represent actual plant operations and training practices	See HR-E3.
HRA-B1	Cat I–II: Define HFEs that represent the impact of human failures at function, system, train, or component level as appropriate, **grouping responses into one HFE if the impact is similar or can be conservatively bounded.** Cat III: **(no grouping).**	See HR-F1.
HRA-B2	Include in the fire PRA model any new fire-related safe shutdown HFEs identified in HRA-A1 and according to HR-F.	See HRA-A1 and HR-F1 and -F2.

Table D-2
Part 4 ASME/ANS PRA Standard requirements for Fire HRA versus EPRI/NRC-RES Fire HRA Guidelines (continued)

ASME/ANS RA-S-2009 Requirements: Fire PRA [1]		Relevant Fire HRA Guidelines Section(s)
HRA Requirements		
HRA-B3	Cat II: Complete HFE definition via accident sequence–specific cues, timing, procedures, and **train-level** tasks required to achieve the response goal. Cat III: Complete HFE definition via accident sequence–specific cues, timing, procedures, and **specific detailed tasks at individual component level (e.g., pumps or valves)** required to achieve the goal of the response.	See HR-F2.
HRA-B4	Cat II: Consistent with ES-C and HR-F, include HFEs for cases where fire-induced failure of **any single instrument** could cause an undesired operator action, or explain basis for inapplicability. Cat III: Include HFEs for cases where fire-induced failure of **up to and including two instruments at a time** could cause an undesired operator action, or explain basis for inapplicability.	See HRA-A3.
HRA-C1	Cat II: Quantify HEPs and account for fire-related effects **using detailed analysis for significant HFEs and conservative estimates for non-significant HFEs**; consider fire-specific impacts to previously modeled HFEs according to timing and PSFs cited in HR-G3, -G4, and -G5, or provide basis for inapplicability. Cat III: Quantify HEPs and account for fire-related effects **using detailed analysis** in accordance with HR-G.	See HR-G1, -G3, -G4, and -G5.
HRA-D1	Cat II: Include recovery actions to restore equipment as needed to provide a more realistic evaluation of **significant accident sequences.** Cat III: Include recovery actions to restore equipment as needed to provide a more realistic evaluation of **modeled accident sequences**.	See HR-H1.

Table D-2
Part 4 ASME/ANS PRA Standard requirements for Fire HRA versus EPRI/NRC-RES Fire HRA Guidelines (continued)

ASME/ANS RA-S-2009 Requirements: Fire PRA [1]		Relevant Fire HRA Guidelines Section(s)
HRA Requirements		
HRA-D2	Address relevant fire-related effects, including those that may preclude a recovery action or alter the way it is performed, and define a basis to support the claim of non-applicability of any of the HR-H2 and HR-H3 requirements.	Section 4.3, Feasibility Assessment. Section 6.1, Recovery Analysis.
HRA-E1	Document unique fire-related influences of the analysis consistent with HR-I, and define/document a basis to support the claim of non-applicability of any of the HR requirements.	Section 7, Documentation.
Other Requirements		
ES-C1	Identify instrumentation relevant to operator actions for which HFEs are defined or modified to address fire PRA scenario context according to SRs HRA-B1 and HRA-B2.	See HRA-B1 and -B2.
ES-C2	Cat II: Identify fire-induced failure of instrumentation, including spurious operation 1) of **any single** instrument associated with each operator action to be addressed and 2) that could cause an undesired operator action related to plant design credited in the PRA. Cat III: Identify fire-induced failure of instrumentation, including spurious operation 1) of **up to and including two instruments at a time** associated with each operator action to be addressed and 2) that could cause an undesired operator action related to plant design credited in the PRA.	See HRA-A3.
FSS-B1	Define and justify conditions assumed to lead to MCR abandonment and/or reliance on ex-control room operator actions, including remote and/or alternate shutdown actions.	Section 3.3.1.4, Main Control Room Abandonment Actions. Section 5.2.8, Alternate Shutdown. Section 4.8, Qualitative Analysis for MCR Abandonment

Table D-2
Part 4 ASME/ANS PRA Standard requirements for Fire HRA versus EPRI/NRC-RES Fire HRA Guidelines (continued)

ASME/ANS RA-S-2009 Requirements: Fire PRA [1]		Relevant Fire HRA Guidelines Section(s)
Other Requirements		
FSS-B2	Cat II: Select one or more fire scenarios such that the MCR abandonment contribution to fire risk can be **realistically characterized**. Cat III: Select one or more fire scenarios such that the MCR abandonment contribution to fire risk can be realistically characterized **and the risk contributions can be correlated to specific ignition sources and locations within the MCR**.	See FSS-B1.
PRM-B2	Verify the dispositioning (settling or putting in order) of the peer review exceptions and deficiencies for the internal events PRA and that this does not adversely affect the fire PRA model development.	Section 7, Documentation.
PRM-B6	Address AS-A and -B in the context of fire scenarios, including effects on equipment, associated cabling, operator actions, and accident progression and timing. Consider fire response procedures as well as emergency operating procedures and abnormal procedures for AS-A5.	Section 3.3, Fire Response Operator Action Categorization; also see SRs under AS-A and -B.
PRM-B9	Where new system models or split fractions are needed, or existing models or split fractions require modification to include fire-induced equipment failures, fire-specific operator actions, and/or spurious actuations, perform the systems analysis portion of the fire PRA model according to HLR-SY-A and HLR-SY-B.	Section 4.2, Information Collection. Section 4.5, HRA Narrative.
PRM-B11	Model all operator actions and operator influences in accordance with the HRA element of this PRA Standard.	See HRA-A through -E.
PRM-B15	Model any new accident progressions beyond the onset of core damage identified according to PRM-B13 to determine the fire-induced LERF in the context of fire scenarios, including effects on system operability/functionality, operator actions, accident progression, and possible containment failures accounting for fire damage to equipment and associated cabling.	Section 2.3, Relationship to Other Fire PRA Tasks.

D.1 References

1. 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*, The American Society of Mechanical Engineers, New York, NY, February 2009.

APPENDIX E
SUMMARY OF TESTING AND REVIEWS

E.1 Objective

Two important steps in the development of the joint EPRI/NRC-RES fire HRA guidelines were subjecting the guidelines to review and testing. Reviews were conducted by an independent peer review team, and a public comment period. The fire HRA processes included in the guidelines were also subjected to hands-on testing. Early in the development process, the draft guidelines were submitted to a panel of independent technical area experts from both industry and within the NRC for their review and feedback. After the peer review was completed, the methods were subjected to hands-on testing at two nuclear power plants. The report was then issued for public comment. As part of the public comment period, the fire HRA guidelines were further tested by the PWR Owner's Group and by some of the method development team.

Each of the review and testing activities was highly valuable to the development of this report. As a result of lessons learned and feedback received from both the peer review and the testing exercises, the methodology and documentation underwent several revisions. The project team is grateful to those who contributed to all of these exercises for their time and invaluable input to this project.

An overview and some details about the review and test activities are provided in the sections that follow.

E.2 Independent Peer Review

The objectives of the peer review were 1) to evaluate the methodology to ensure that it is technically sound and will meet the needs of the intended users, 2) to identify any significant deficiencies in the proposed approach early enough in the development process that they could be addressed and the methodology modified in time to meet the needs of the intended users, and 3) to ensure that the methodology is documented in a manner that is clear, concise, logical, and usable for the intended audience.

Along with the draft copy of the document, the independent review panel members were given a set of instructions that included the following questions to keep in mind while they were conducting their review:

1. Is the technical approach sound and reasonable?
2. Are the selected HRA models appropriate for the application?
3. Are the assumptions presented in this methodology reasonable?
4. Does the guidance meet its stated objectives?
5. Is the writing clear and of acceptable quality?

6. Is the proposed methodology usable and understandable?
7. Is uncertainty adequately addressed?
8. Can you provide any suggestions for reducing the uncertainty that is present?

After independently reviewing the document, the peer reviewers were asked to participate in a meeting between the entire peer review panel and the guideline development team. The purpose of this meeting was to give the peer review panel an opportunity to ask the guideline development team questions and to clear up any ambiguities they may have encountered in their initial review of the document. This meeting also gave the peer review panel an opportunity to share their initial feedback and impressions of the document. After the meeting, each reviewer documented their feedback and submitted this documentation to the guidance development team. Each comment from the peer review panel was reviewed and assessed by the project team. Based on these comments and the feedback received during the peer review meeting, several changes were made to the document and to the scoping trees to prepare them for hands-on testing.

E.3 Testing Objectives and Scope

After the peer review was completed, the guidelines were subjected to two rounds of hands-on testing. Testing was included in the process because the guideline development team felt that it was necessary to put the methods through a process to help determine whether the assumptions used in developing the guidance would hold up when applied to actual plant-specific fire scenarios. Subjecting the methods to testing also provided a high level "reasonableness" check for the human error probability (HEP) values generated by the method. Other objectives of testing the method included identifying any limitations and inaccuracies, and assessing the method's usability when practically applied. The testing conducted as part of this project did not constitute a verification or validation of the methodology results. Because of the limited availability of adequate detailed HRA data, a quality verification and validation (V&V) analysis is not practical and is therefore outside the scope of this analysis.

For the purposes of this project, *reasonableness* was defined as yielding human error probability (HEP) values that a) were generally *logical from a probabilistic risk assessment (PRA) perspective,* b) were not lower than values derived in the test plant's internal events analysis for the same action, and c) were not higher than the screening values obtained using the NUREG/CR-6850 HRA screening method [1]. The underlying assumption behind this definition of *reasonableness* is that the probability of an operator committing an error when conducting a given action in most cases should increase when fire effects are introduced. Conversely, the probability of an error should not decrease given that fire effects are present. If the fire HRA methodology yields a lower HEP than the one yielded by the plant's internal events HRA, it would suggest that the assumptions in one of the two analyses are incorrect. A key point to remember is that the internal events HRA analyses and the fire HRA analyses are performed using different methods and therefore their results are not and should not be expected to be in perfect alignment. However, both analyses should hold up to part *a)* of the reasonableness assumption of being generally logical from a PRA perspective. If both analyses yield logical results, the fire HRA methodology should yield higher HEP results.

Testing exercises were conducted at two nuclear power plants, one of which was a BWR and the other a PWR. They are identified in this summary as *Plant #1* and *Plant #2*.

- Plant #1: Two-unit BWR manufactured by General Electric.
- Plant #2: Two-unit PWR manufactured by Westinghouse.

For each exercise, a team of three or four members of the EPRI/NRC-RES Fire HRA project team visited the plant sites and met with key plant PRA and training personnel.

The test plan, the testing scenarios, and the lessons learned from the testing exercise are described in the sections that follow.

E.3.1 Test Plan

Objective:

Exercise fire HRA method broadly enough to evaluate the adequacy of analysis guidance and test the applicability of scoping and detailed HRA approaches.

Results should identify areas where guidance is insufficient or where improvements to the logic structure of quantification approaches are needed.

In particular, the following items should be tested:

1. Test the scoping flow charts by applying the system to at least one action for each branch in the structure.
    a. Verify that the qualitative questions are appropriate.
    b. Check the quantification values for reasonableness (i.e., that the new HEP values are not lower than the internal events values or greater than the screening values).
2. If possible, also apply the EPRI HRA approach and compare with the internal events assessment.

    The reasonableness of the obtained HEPs, both in terms of face validity and the relative ranking of HEPs across the different types of conditions, should be evaluated. The method will be tested for both a BWR and a PWR. There is an assumption that there will be an existing fire PRA available at the selected plants or at least a fire PRA that has developed the PRA models to the extent that the human failure events (HFEs) have been identified and included in the PRA models.

Step 1. Prior to plant visit:

- Obtain a copy of existing fire PRAs and relevant plant procedures (emergency operating procedures [EOPs], fire procedures, and alarm procedures) for review (two weeks before plant visit).
- Evaluate existing identification and definition of HFE results. Characterize the level of the study progress relative to the NUREG/CR-6850 task structure. Do the fire PRA models include the types of actions needed to test the fire HRA method? Determine whether additional identification and definition steps are needed. To the extent possible, independently test the fire HRA method’s identification and definition process. Try to apply the feasibility criteria in the identification and definition step.

- If the NUREG/CR-6850 HRA screening approach was used, revisit the screening analysis to determine whether the revised screening approach provided in the fire HRA method would lead to different results for long-term events.
- Identify an initial set of HFEs for quantification using the scoping and/or detailed approaches. Testing should include both risk-significant and non-risk-significant actions (if relevant information on these actions can be obtained). The set of HFEs should include the following:
    1. Existing internal events in control room HFEs
        a. No expected fire effects in terms of smoke
        b. No expected fire effects on instrumentation or control
        c. Potential fire effects on instrumentation (potential EOCs or EOOs)
    2. Existing internal events ex-control room HFEs
        a. No expected fire effects ex-control room in terms of smoke and so on
        b. Potential fire/smoke effects ex-control room
    3. Fire response actions
        a. Fire manual actions (FMAs), including preemptive and reactive actions according to NUREG-1852 [2]
        b. HFEs with potential fire effects on instrumentation (EOC and EOOs)
    4. HFE(s) from a MCR abandonment due to habitability scenario
    5. HFE(s) from a scenario that might require use of the alternate shutdown panel for control, even if conditions did not lead to a need for abandonment of the MCR
- If possible, characterize recovery actions, dependencies between actions, and uncertainty range in the result.

Step 2. Visit plant (two days at plant) and obtain support from plant PRA and training staff to:

- Perform qualitative analysis of selected actions, including obtaining information on event timing (occurrence of cues for the actions, estimates of time available, and estimates of time to accomplish the actions) and other PSFs given the expected plant conditions.
- Revise selected HFEs if some events are not suitable for testing.
- Apply scoping quantification approach and, where appropriate, the EPRI HRA approach to selected HFEs.
    – Support will be needed from training and other plant personnel to make scoping path selections and provide needed information (e.g., for information on requirements for ex-control room actions).
    – If the detailed methods are to be applied to at least some extent, significant detailed information is required to achieve a realistic analysis. Analysts will need to be well prepared to collect the relevant information for a given HFE and obtain the needed plant support.

Step 3. After the plant visit:

- Document results identifying problem areas.
- Compare scoping, detailed, and existing plant HRA results (if any) for HFEs addressed in the test and those already analyzed for the fire PRA.

Step 4. Review analysis and results with plant:

After the HEPs have been reviewed and quantified by the team, the results need to be provided to the plant and feedback requested. For example, are the results what you need to complete the fire PRA? Are the results reasonable, and are there any actions that you would require detailed analysis on based on the results from the scoping trees? What are your thoughts on the method application?

E.3.2 Testing Scenarios Plant #1

Prior to the plant visit, the project team was given a set of plant procedures. A set of five scenarios was proposed for use in evaluating the scoping methodology on Plant #1, including one or more scenarios in the five categories of 1) existing internal events important to the fire PRA, 2) new fire PRA HEP not in the internal events PRA, 3) spurious induced scenario, 4) spurious/false indication causes inappropriate operator action, and 5) main control room abandonment.

These scenarios are summarized next.

Existing internal events HEPs important to fire PRA scenario. Fire starts in the turbine building, causing loss of offsite power and of an emergency diesel; the redundant emergency diesel fails to start. The emergency condensers successfully actuate on high RPV pressure, there is no stuck-open ERV, and there is no major increase in reactor recirculation pump leakage (no LOCA). The operator actions shown in Figure E-1 are important to reach a success state.

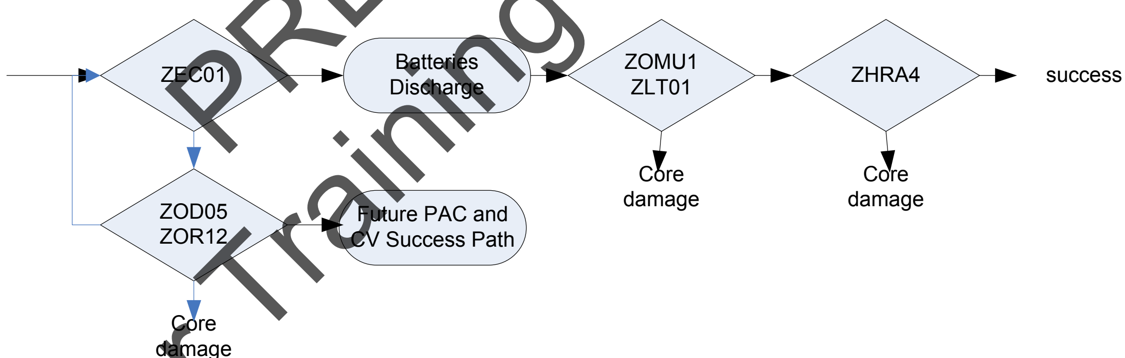


Figure E-1
Operator actions for success state

- ZEC01—controlling emergency condensers according to procedures, which instruct operators to stay within pressure band and cooldown rate. Operators will isolate one emergency condenser (EC) relatively early, eventually isolate the second, and then unisolate the second EC to control RPV pressure (and cooldown rate).
  - Procedures: N1-EOP-2 “RPV Control” and SOP-1
  - Cues/instrumentation: PI-39-113A and 39A on the main control board

  - Actions are from the control room
  - Time window: 50 minutes
    - Success of this action ensures that an EC is used to control pressure, heat removal, and inventory for several hours until EC makeup is required with the diesel fire pump (see ZLT01 below) and the batteries discharge (see ZHRA1 below).
    - Failure of this action means that pressure is not controlled, ERVs will open, and eventually that sufficient inventory will be lost, resulting in blowdown at the top of active fuel or a lower level.

- ZOMU1 (with ZOU01) and ZLT01—makeup to the ECs is required in order to continue EC success for 24 hours. Procedures instruct operators to control EC makeup (ZZOMU1 models this but assumes that they isolate per cooldown and then ZOU01 or 02 is required to ensure that the valve is opened—these should probably by combined into one HEP) so as not to waste makeup water (FCV from makeup tank to EC shell fails open, allowing makeup tank to overfill shell and flow out the overflow to drains), but failure to conduct this only shortens the time window for ZLT01.
  - Procedures: ZOMU1 N1-SOP-33A and SOP-21.1, Table 21.1-4
  - Procedures: ZLT01 N1-SOP-33A and SOP-21.1 at the bottom
  - Cues/instrumentation: EC shell, makeup tank levels, procedure directions in CR
  - An operator is required to be at EC makeup tanks (El 369 of TB)
  - Time window: within ½ hour for ZOMU1 and between 2 and 18 hours after fire initiator for ZLT01 (depends on ZOMU1 and availability of EC shells)
    - Success means that an EC can control pressure, heat removal, and inventory for 24 hours.
    - Failure is assumed to result in core damage although, with future modifications and the use of a portable charger, a success path is possible as described previously for ZEC01.

- ZHRA4—when batteries discharge (4 to 8 hours, depending on load shedding, ZOLS1), RPV pressure and level can be monitored for plant control purposes in the east/west instrument room and is assumed necessary to reach a success state unless the new modifications (coming) have been implemented (portable charger allows ERV to stay open and ensures instrumentation in the CR).
  - Procedures: SOP-21.1 for ZOLS1 and SOP-29.1, Alternate Instrumentation
  - Cues/instrumentation: loss of CR instruments and battery voltage
  - An operator is required to be in east/west instrument rooms (El 281 of RB)
  - Time window: 4 hours after fire initiator if no load shedding
    - Success means that plant control is retained without DC power

Failure means that operators have lost control and core damage is assumed

New fire PRA HEP not in the internal events PRA. There are potentially a few new operator actions not in the internal events PRA but in SOP-21.1 and SOP-21.2. These could become important during the detailed fire modeling and scenario development. Consider HRA1, Operator Copes During SBO Without Instrumentation Reactor Bldg SOP-29) (DC load shedding) or actions required to transfer control to remote locations.

Spurious induced scenario. There are several spurious induced equipment failures identified at Test Plant #1, the most important of which are most likely associated with several single main feedwater equipment failures that could result in an RPV overfill. Overfill would take out the main condenser, if available initially (water in the steam lines); there are probably fires that take out the main condenser and start overfill. EC actuation with water in the EC steam lines could result in EC isolation (assumed in the PRA).

In this scenario the fire starts in the turbine building, causing FCV-29-137 or FCV-29-141 to fail open. There are two key operator actions associated with this scenario:

- ZFL03—operators prevent overfill given MSIV closure or loss of instrument air
  - Procedures: N1-SOP-1
  - Cues/instrumentation: RPV level
  - Main control board
  - Time window: 3 minutes
- ZFL02—operators prevent overfill given general transient
  - Procedures: N1-SOP-1
  - Cues/instrumentation: RPV level
  - Main control board
  - Time window: 3 minutes
- ZFL01—operators recover an EC
  - Procedures: N1-SOP-1
  - Cues/instrumentation: RPV level and pressure
  - Main control board
  - Time window: 50 minutes

Spurious/false indication causes inappropriate operator action fire scenario. Fire starts in reactor building (e.g., R2A, R3A, or R4A) or turbine building (T3B, El 261 West), impacting cables to Annunciator K1-4-3 (EC11) and K1-4-5 (EC12); false indication of EC line break. (Signal on X of Y channels, need to check in simulator.) The turbine building event is likely the most important because fires in T3B can also impact feedwater and/or normal AC power, making the ECs important. Plant #1 assumed that ECs would become unavailable without recovery and therefore did not pursue a more detailed evaluation.

Control room abandonment fire scenario. For the EPRI/NRC methodology test, two MCR panel fires are modified by assuming that the fires produce sufficient smoke and toxic fumes to cause the operators to abandon the control room or put on SCBA gear in the evolution, even though the amount of combustible material in the panels is small. Furthermore, it is assumed that the HVAC air circulation system is off. The operators take actions locally and at the safe shutdown panel(s).

In the C3Ga scenario, the fire in Panels A4 and A5 is assumed to cause failures in breaker control switch circuits on these main control room panels such that Buses 101, 102, and 103 and Power Boards 11 and 12 all lose power because of potential combinations of spurious breaker openings and other failures to breaker controls so that all power feeds are open to these buses/boards (including no power from the diesels). For the postulated fires, there is not likely to be irreparable damage to the buses/boards; they have simply lost all of their power feeds, causing loss of all loads on these buses/boards. Offsite power actually remains available—it needs to be provided again to the buses/boards by reclosing necessary breakers, although it is assumed that this cannot be done from the main control room because of damage to the breaker switch controls on Panels A4 and A5.

In the C3Na fire scenario, occurring in the area of the feedwater controls on the panels in the main control room, the fire causes a ramping up of the feedwater supply to the reactor vessel (e.g., via spuriously increasing the pump speeds and/or fully opening the feedwater regulation valves) and an overfill of the vessel. For initial fire PRA modeling purposes, this is assumed to result in an automatic plant trip, loss of condenser, likely loss of feedwater (either because of effects on the control circuits and/or a high-level trip of the pumps or operator shutdown and isolation of the system as directed in N1-SOP-1, Reactor Scram), and loss of control rod drive (CRD) initial injection (no credit is given in the initial fire PRA model for early CRD injection, and N1-SOP-1 directs securing of CRD pumps by the operator in such a situation). In addition, the overfill condition is assumed to make the ECs unavailable or at least ineffective due to the vessel overfill condition. It is further assumed that the smoke and conditions of the fire are sufficient to cause the operators to abandon the control room.

E.3.3 Testing Scenarios Plant #2

Prior to the plant visit, an engineer from Plant #2 gave the project team a set of plant procedures as well as four detailed fire scenario descriptions intended to challenge the scoping HRA flowcharts in different ways. The four scenarios chosen were modeled in the plant's fire PRA and needed analysis beyond a screening analysis to obtain a better HEP. These scenarios had detailed fire modeling available, and the impacts to instrumentation were known.

Table E-1 lists the scenarios tested, the scenario's classification, and the flowcharts that were used to test them.

Table E-1
Classification and flowcharts used for the scenarios tested

Scenario Number	Description	Classification	Flowcharts Used for Testing
1	Locally open 8804 A/B for high-pressure recirculation following a spurious PORV LOCA	Internal events action but not currently modeled in PRA	New and existing ex-CR action
2	Heat load reduction/swap to alternate CCW train	Internal events EOP action	New and existing MCR action
3	CP M-10 (fire procedure) directed action to manually control LCV110/111	New operator manual action	New and existing ex-CR action
4	Operator responses to spurious 4-kV Bus F ground annunciator	Undesired operator response action	Spurious EOO and spurious EOC
5	Operator fails to deenergize PORV/closed to mitigate spurious operation during MCR abandonment	New action added for fire PRA	MCR abandonment

Scenario 1: Locally open 8804 A/B for high-pressure recirculation following a spurious PORV LOCA. The fire starts in a transformer and impacts targets in the plume and vertical trays adjacent to the flames. Important impacts involve a spurious opening of the startup supply breaker to vital buses and other bus startup equipment.

Critical impacts are to spuriously open a PORV and disable its block valve. Attempts to manually close associated (8000) prior to auto safety injection fail.

Operator action: locally open 8804A or B prior to depletion of RWST.

HFE scenario description:

1. Assumptions/initial conditions including initiating event: reactor trip, spuriously opened PORV results in a small LOCA, no containment spray required.
2. Preceding functional failures and successes: RT successful, TT successful, auxiliary feedwater successful, Bus G ECCS equipment is impacted by fire.
3. Operator actions preceding the key action: controlled ECCS flow to match makeup flow with leakage rate. Tripped RHR pumps.
4. Symptoms/indications (other than cue): PK03 (RWST level <33%).
5. Consequences of success or failure: if unsuccessful, core damage.
6. Operator action success criteria: align cold leg recirculation via 8804A/B.
7. Time cue is received: 180 minutes.

3. Manipulation time: 25 minutes.
4. T_{sw} = 120 minutes +180 minutes.
5. $T_w = T_{sw} - T_m - T_{delay}$ = 95 minutes.

Scenario 2: Heat load reduction/swap to alternate CCW train. The fire starts in the 125-VDC cabinet and, after a short progression, results in damage to all equipment in the fire zone.

HFE scenario description:

1. Assumptions/initial conditions including initiating event: fire starts in cabinet, reactor trip occurs simultaneously with fire alarm actuation in the control room, CCW outlet valve spuriously closes, and CCW flow is lost.
2. Preceding functional failures and successes: fire damages equipment in room. Includes most SSD equipment associated with Bus F.
3. Operator actions preceding the key action: immediate operator actions, action to open spuriously closed valve is directed in CP M-10. This recovery is unlikely to occur prior to EOP action to align standby train.
4. Symptoms/indications (other than cue): numerous annunciators/alarms from reactor trip, loss of some indication due to fire; may see other annunciators actuate as a result of CCW flow loss.
5. Consequences of success or failure: overheat the CCW system to above 140 degrees, and fails its loads.
6. Operator action success criteria: place the standby heat exchanger in service with flow from an ASW pump.
7. Time cue is received: N/A.
8. Manipulation time: about 5 minutes.
9. T_{sw} = 90 minutes.
10. $T_w = T_{sw} - T_m - T_{delay}$ = 85.

Cue: fire alarm actuated.

Scenario 3: CP M-10 directed action to manually control LCV110/111.

HFE scenario description:

1. Assumptions/initial conditions including initiating event: fire starts in electrical cabinet; reactor trip occurs simultaneously with fire alarm actuation in the control room. AFW Pumps 1 and 2 are impacted, as is LCV.
2. Preceding functional failures and successes: fire damages equipment in room due to hot gas layer development (~20 minutes). Potential equipment impacts include spurious closure of CCW thermal barrier cooling supply valves, CCW heat exchanger outlet valves. Potential loss of offsite power due to spurious CB opening. Impact to diesel generator, 480-V switchgear ventilation, and AFW FTs. AFW Pumps 1 and 2 are available.
3. Operator actions preceding the key action: immediate operator actions IAW E-0.

4. Symptoms/indications (other than cue): RCS temperature and pressure increasing.
5. Consequences of success or failure: core uncovery.
6. Operator action success criteria: successfully operate LCV to control level in SG prior to core uncovery.
7. Time cue is received: N/A.
8. Manipulation time: about 15 minutes (although continuous control is required).
9. T_{sw}= 135 minutes.
10. $T_w = T_{sw} - T_m - T_{delay}$ = 120 minutes.

Cue: fire alarm actuated; decreasing SG level; all SG and level instrumentation available.

Scenario 4: Operator responses to spurious 4-kV Bus F ground annunciator. To test the spurious EOO and EOC flowcharts, the plant provided the following example of an HFE it identified in its review of ARP procedures. The review of the ARP was performed in accordance with the guidance in Section 3 of the draft guidelines. The complete fire scenario was not provided or defined because this action has not yet been incorporated into the fire PRA. The analysis for this HFE focused on how to use the flowchart; it was concluded that the spurious flowcharts need additional clarification.

Scenario description:

The following annunciator spuriously actuates in the control room: AR PK-18-23 – 4-kV Bus F ground OC alarm.

The 4-kV Bus F ground annunciator is received based on any of the following component failures

- Charging pump failure
- SI pump failure
- ASW pump failure
- AFW pump failure
- CCW pump failure
- 480 v Bus 1F failure

Step 5 of the procedure consists of the following steps:

5.1 Check annunciator typewriter printout for equipment having the group.

5.2 Shut down the running pump, or open the 4-kV breaker 52-HF-10 feeding 480-V Bus F.

5.3 Notify maintenance services to locate and repair defective circuit.

The fire scenario has not been defined such that it is known which device will cause the spurious alarm. However, stopping any of the pumps will be considered an undesired response action.

Scenario 5: MCR abandonment scenario. The test plant is not modeling MCR abandonment scenarios in its fire PRA model. Therefore, the team created a fictitious scenario to test the MCR control room abandonment flowcharts.

Scenario description:

Operator fails to deenergize PORV/closed to mitigate spurious operation during MCR abandonment. The fire is in A-7, cable spreading room.

There is smoke in the control room, and NUREG/CR-6850 MCR abandonment criteria are met.

T_{sw} = 180 minutes.

This action is proceduralized in OP AP-8A, control room abandonment Step 14.

The cues for this action are RCS wide range pressure at hot shutdown panel, HSDP, and DSDP.

E.3.4 Operator Interviews

On the first day of the plant visit, the HRA team—along with the plant engineer—met with two reactor operators to gain insights on how they would execute the procedures given the specific fire scenarios. The intention was to find areas in which the operators could potentially be tripped up by the circumstances of the scenarios and to figure out whether the assumptions made when developing the scenarios were valid. In general, the operators believed in all cases that the actions could be successfully carried out, given all circumstances presented. This was as expected, given that operators should generally be confident about their abilities to safely handle any situation that develops in the plant.

After the interviews with the operators, the team sat down with the plant engineer and stepped through the flowcharts using the scenarios provided. This exercise gave the team several insights on how the logic in the charts held up, given realistic scenarios. The plant engineer also gave the team some suggestions on minor adjustments that could be made to improve the charts.

E.3.5 Testing Results/Lessons Learned

Overall, the testing exercises were highly beneficial to the fire HRA guidance development team. The team got an interim look at how the flowcharts performed, given realistic scenarios. The team also had the opportunity to introduce the methods to some of their potential users and get their feedback. Personnel at both plants posed several insightful questions and made valuable suggestions on how to improve the scoping flowcharts. The interviews with plant personnel prior to testing the flowcharts also gave the team insights on how the operators are trained and how they use their procedures and instruments to diagnose problems. This gave the team a better idea of how well the scoping trees actually modeled operator actions.

For example, during the interviews at Plant #2, the operators emphasized that they would not open the fire procedures until they had completed the EOPs because they trusted that the EOPs would guide them correctly.

Several of the questions asked by plant personnel resulted in changes to the scoping trees. For example, the plant engineer at Plant #2 asked a question during testing about whether an action required personnel to travel through smoky areas. This resulted is the addition of a question to the ex-MCR actions flowchart about whether the fire was in the vicinity of the action and

whether the travel path was accessible. Branches were added to the flowcharts to account for short time events based on a comment made at one of the plants during testing. Confusing language in the scoping trees was also identified by the plant engineers, which resulted in several changes and clarifications in wording.

In general, the HEPs derived at Plant #1 through the use of the scoping flowcharts were conservative compared to the internal events HEPs. One of the observations made by a plant engineer at Plant #1 was that perhaps the 100% time margin requirement contained in the flowcharts at the time was inappropriate for longer term actions. This requirement may have contributed to the overly conservative HEP results.

Overall, the plant engineers at both plants thought that the scoping tree guidance was useful and were appreciative of the team's efforts to develop guidance for performing this part of their fire PRA. The scoping trees underwent several iterations after the peer review and both the first and second round of testing exercises to get to the resulting trees included in the guidance. Many of the improvements that resulted from these iterations can be attributed to the input provided by the test plants.

E.4 References

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

   Note: When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following as well:

   Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.

2. U.S. Nuclear Regulatory Commission. NUREG-1852, *Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire*, October 2007.

APPENDIX F
JUSTIFICATION FOR SCOPING APPROACH

This appendix addresses the basis for the scoping quantitative approach. Issues include the use of time margins, the PSFs addressed implicitly and explicitly, and the basis for the HEP values assigned through the use of the flowcharts.

F.1 Time Margin

The development and definition of *time margin* are provided in Section 4.6.2. The time margin (i.e., the ratio between the available time and the time required, essentially the extra time available) is included not only to account for potential shortcomings in the feasibility assessment, but also to account for potential variability in crew response times. Furthermore, time for recovery is implicitly accounted for in extra time being available for performing the action.

The feasibility assessment gives a close approximation of the time required by an average crew; however, it does not address the reliability of the action. Time margins are used to account for potential variability in crew response times in determining HEPs using the scoping flowcharts. The larger the time margin, the more likely the variability in crew performance will be enveloped and the lower the HEPs that can be assigned.

A time margin also provides a safety margin against the potentially poor performance of expert judgment in predicting the amount of time required for aspects of the response that cannot be accurately accounted for in the feasibility assessment, especially under stress [1]. Specifically, the extra time is included to account for potential unexpected fire effects and variabilities such as the following:

- Individual differences
- Crew differences
- Variations in fire type and related plant conditions
- Factors unable to be recreated in the feasibility assessment

NUREG-1852 [2] provides guidance on developing timelines to help with the assessment of the time margins that can be assumed to be available.

In general, for the scoping HRA quantification, a time margin of at least 100% or a factor of 2 additional time must be available to provide a safety margin and allow assignment of an optimal HEP for the conditions present. The basic time margin of 100% was established based on discussion in Appendix B of NUREG-1852 [2] in which an expert panel was convened to determine appropriate time margins for operator manual actions. During these meetings, a factor of 2 was decided upon to be sufficient for allowing an appropriate safety margin of time. Although this factor was established for operator manual actions to achieve and maintain fire hot shutdown, the application of the factor of 2 rule is applied a bit more broadly for the scoping fire

HRA approach in which the actions may be performed in the MCR. This decision was made because the scoping fire HRA quantification approach should be slightly more conservative than a detailed approach to account for PSFs not directly considered.

The application of time margins in the scoping flowcharts does not allow credit for actions that must be performed with a time margin less than 50%. Therefore, the calculated HEP may demonstrate a large change from a time margin of 50% or greater to the HEP of 1.0 if the time margin is less than 50%. Many methods rely on a binary decision point where the parameter is not clear cut and could result in large differences in the final HEP. The standard way to deal with these cases is to perform a sensitivity study and a detailed analysis if the time margin is close to 50% and the results are sensitive to the assigned HEP. If it appears that significant variability in crew response times is possible, analysts should at least initially select conservative estimates of response times and refine the data later should the HFE significantly impact the fire PRA model quantification results (i.e., dominate the cutsets). See further discussion in Section 4.6.2.

F.2 Performance Shaping Factors

In the construction of the scoping fire HRA quantification, the PSFs explicitly addressed were those deemed to be the most relevant for the fire context that would account for variation in crew performance. In particular, the concern was with factors that were thought to lead to the greatest variation in crew response and the desire to encompass the stressors affecting human performance of actions taken during a fire. The PSFs considered for inclusion were based on those identified by ASME/ANS Standard Requirement HR-G3 [3] and discussed in NUREG/CR-6850 [4], which are based on reviews of fire events.

Before entering the scoping flowcharts, there is a minimum set of PSF criteria that must be met. As described in Section 5 of this report, meeting these minimum criteria does not preclude the consideration of these PSFs later in quantification. These criteria are important because they allow the scoping approach to be appropriately applied to the HFE and associated scenario by limiting the context. It is these minimum criteria combined with a few elements of the selection scheme discussed in Section 5.2.5 that allow the scoping approach to address only certain performance influencing factors. First, plant procedures must be in place to support the diagnosis and execution of the operators' action(s) being modeled, unless the action can be assumed to be skill-of-the-craft.[20] Next, the operators should be trained on the use of the procedures and the actions being performed. This training on the action should cover all steps of the action, including any coordination of team members and communications that may be required. Finally, any equipment and tools that would be required for the completion of the action must be available and accessible.

When this minimum set of criteria has been established, there are several PSFs addressed explicitly within the flowcharts. Some of these PSFs are covered within the flowcharts because they were likely unable to be accounted for in the feasibility assessment. In general, the PSFs included in the flowcharts are explicitly included because it is expected that these PSFs could induce significant variability in crew performance and response times. It is important that they are adequately addressed.

[20] In the case of recovery following an EOO or EOC due to spurious instrumentation, specific procedural guidance directing the recovery may not be necessary. However, an argument must be made as to why existing procedures, training, and available cues would be adequate to support recovery of the error(s), and this argument should be consistent with ASME/ANS Requirements HR-H1 and HR-H2 [3].

The PSFs explicitly addressed through the flowcharts include the following:

- **Diagnostic complexity.** The diagnostic complexity is assessed in a yes-no framework. To evaluate this factor, it is asked whether the procedures match the scenario (i.e., the expected pattern of cues will be consistent with the procedures that lead to a correct response). If the cues received do not match the procedures, it is assumed that a much more complex diagnostic scenario is in play, and the HEP is automatically set to 1.0. If the procedures do match the situation and the cues, the diagnosis of the event is assumed to be relatively straightforward.
- **Execution complexity.** The execution complexity of the response is quantified at two levels, either high or low. Section 5.2.3 of this report details what is required in deciding whether the complexity should be assessed at the high or low level.
- **Likely status of the fire (ongoing or extinguished).** The likely status of the fire is measured based on the time since the initiating event. For conservative estimates, the initiating event is considered to coincide with the start of the fire. Based on information in Appendix P of NUREG/CR-6850 [4] and FAQ-08-0050 [5], most fires are extinguished or contained within 70 minutes of the start of the fire.[21] The measurement of time since the start of fire is a contextual variable included within the scoping flowcharts because it addresses other important factors that may be critical but that are not directly asked within the scoping flowcharts. For instance, if an action needs to be completed before the fire has been fully suppressed, additional factors not directly addressed within the flowcharts may inhibit the ability to perform the action (e.g., fire in the path that limits accessibility to the action site; increased distractions in the MCR from implementing fire procedures and coordinating and tracking the ongoing firefighting). Furthermore, if the fire has not been fully suppressed and fire effects may be ongoing, additional PSFs should be evaluated in determining an appropriate HEP level (e.g., level of smoke or other hazardous toxin in the air). Therefore, these additional PSFs are asked only in instances in which the fire has not been suppressed.
- **Amount of available time.** This is an additional timing question posed in the scoping approach to distinguish between long-term and short-term events. The time available, also known as the *time window*, is the amount of time from the occurrence of the relevant cues that is available to diagnose a problem and complete the action; therefore, it includes time for diagnosis, execution, and any remaining extra time (e.g., time for recovery). Within the scoping flowcharts, a distinction is made between long-term events (i.e., events that have more than a 30-minute time available) and short-term events. The distinction is based on the simple assumption that shorter time window events could be more susceptible or sensitive to minor distractions and diversions related to the occurrence of the fire than longer timeframe events. With only a relatively small time window, such distractions could have a proportionally greater impact than when larger timeframe events are involved. These requirements are intended to account for potential distractions related to the fire (even if it has been extinguished) that could significantly delay response times and pose a greater threat to completing actions for short-term events.

[21] An important exception to this 70-minute rule is more challenging fires such as fires of turbine generators, outdoor transformers, high-energy arcing faults, and flammable gas fires. For modeling of actions during these events, the analyst should always assume that the cue occurs before the fire has been suppressed, regardless of when the cues occur relative to the start of the fire.

- **Environmental condition (specifically, level of smoke or other hazardous gas in the area).** The level of smoke or other hazardous gases or toxins in the area can cause additional stress by lowering the visibility and/or by requiring that special equipment (e.g., SCBA) be worn. In the presence of an ongoing fire, these factors are especially a concern. Furthermore, their impact on a crew performing the necessary action may be difficult to estimate in the feasibility assessment.
- **Wearing of special equipment.** The requirement to wear special equipment (e.g., SCBA) may negatively affect the physical performance of the team member or hinder communications between team members.
- **Accessibility of location.** The ability to access the location may be constrained due to ongoing fire effects at the action location or in its path. Fire effects limiting the ability to proceed to or through an area may include the presence of flames, intolerable heat, water on the floor or in the area, high amounts of smoke or other toxin impeding breathing or visibility, and illumination of the area.
- **Time margin.** As discussed in Section F.1, a measure of time margin is included to account for the uncertainty not directly addressed through the feasibility assessment or other PSFs included within the flowcharts.

F.3 HEP Values

F.3.1 Base HEP Value

The scoping fire HRA approach differs from the screening fire HRA approach in an effort to reduce undue conservatism by allowing credit for conditions of various PSFs and for substantial time margins. Therefore, the HEPs assigned are based on the level of the PSFs and can be compared to other traditional HRA methods used for internal events analysis. The initial HEP values were set based on expert judgment. The values were then compared against existing methods as a reasonableness check.

A HEP value of 1E-3 is set for the base fire scenario in which the conditions represent the best possible for the fire context. In this manner, this HEP is the best achievable in the scoping fire HRA approach. The value of 1E-3 is defined in ATHEANA [6] as the value for "The operator is 'Extremely Unlikely' to fail"; this definition is consistent with how the value is used in the scoping approach. The following specific conditions are required to attain the HEP of 1E-3:

- Minimum PSF criteria have been met prior to entering the flowcharts
- Procedures match the scenario, indicating a straightforward diagnostic situation
- Diagnosis and execution take place within the MCR
- Fire effects are not ongoing
- Available time is greater than 30 minutes
- Execution complexity is low
- Time margin is at least 100%

Although the baseline, or best case, HEP assigned in the scoping fire HRA approach does not have separate values for the diagnosis and execution components, it can be compared to the individual HEPs for diagnosis and action from SPAR-H [7], THERP [8], and ASEP [9]. SPAR-H, in particular, was chosen for this comparison because the authors have made a concerted effort to align their HEPs with other methods [7, 10]. The comparison of the scoping fire HRA approach to the internal events HRA methods was made for the select case for which the conditions resemble those of an internal events analysis (i.e., the fire effects are not ongoing). Because these methods do not explicitly address obtaining HEPs under fire conditions, we use them only to show consistency with the "baseline" HEP.

In consideration of the diagnosis component, assuming that the diagnosis-related conditions noted previously are met (i.e., it is a straightforward and relatively simple action, based on the assessment of the scenario matching the procedures), the argument is made that the base HEP of 1E-3 is consistent with the SPAR-H assessment of an HEP of 1E-3 for similar conditions, which is the nominal value of 1E-2 adjusted downward to reflect the availability of extra time. If the nominal HEP from SPAR-H is also adjusted downward to reflect low complexity ("obvious diagnosis" in SPAR-H), which is consistent with the conditions for the base or optimal case in the scoping fire HRA approach, an HEP of 1E-4 is obtained. This implies that the base HEP for the scoping fire HRA approach (fire is no longer ongoing, and essentially optimal conditions are present) is conservative by an order of magnitude relative to similar conditions (except that a fire-induced initiating event was not involved) in SPAR-H.

The base HEP in the scoping approach is also consistent with that assigned through the use of ASEP [9] for diagnosis within the time allowed if the time for diagnosis is equal to 30 minutes. It also matches the HEP for diagnosis if time is equal to 20 minutes and the lower bound is used. Justification for the use of the lower bound in this instance is assumed because the diagnosis of the action is relatively simple and straightforward, with more than adequate time available. It is believed that the positive conditions assumed for the base scoping value, including the assumption of a longer timeframe event (>30 minutes available) and a 100% time margin, parallel the conditions in ASEP that produce a similar value. Furthermore, it should also be noted that the HEPs produced from ASEP [9] are argued to be conservative values.

For quantification of the execution portion of the HEP, SPAR-H [7] stipulates a value of 1E-3 for executing actions under nominal conditions and would produce even lower values if the conditions assumed for the scoping fire HRA approach were treated in SPAR-H. ASEP [9] provides somewhat higher HEPs for executing actions relative to the scoping fire HRA approach base value but also builds in the ability to reduce these values significantly (i.e., to 4E-3) when it is a simple task, with moderate stress and a second crew member to verify the action. Therefore, it is argued that there is not significant disagreement between the scoping approach and ASEP.

Similarly, walking through the tables in Chapter 20 of the THERP manual [8] in the following manner results in an HEP on the order of 1E-3:

1. The search scheme of Figure 20-1 directs the analyst to Table 20-7 to quantify the execution portion of the action based on the error being one of omission and written, procedural direction being available.

2. Table 20-7 offers an HEP value of 1E-3 for written procedures being in use that consist of a short list with check-off provisions or 3E-3 for a list without check-off provisions.

These HEPs are assumed to be suitable even for local actions, rather than the simple MCR actions being addressed in the nominal conditions for the scoping fire approach.

Therefore, the assumption of a base HEP (which requires a rigorous set of conditions to be met; see list above) of 1E-3 (including diagnosis and execution) is argued to not be largely different from those obtained for similar conditions using existing methods such as ATHEANA [6], THERP [8], ASEP [9], and SPAR-H [7] and is likely to be conservative relative to the values obtained using the other methods.

F.3.2 HEP Multipliers for PSFs

As conditions deteriorate from this base condition, Table F-1 shows the multipliers applied to the HEP depending on the level of the PSFs. These multipliers were used in the determination of the HEP values displayed in the HEP lookup tables featured in Section 5 of this report. In the determination of the HEPs, as the conditions of the scenarios deteriorated or became more negative (e.g., time margin of less than 100% or high smoke levels requiring the crew to wear SCBAs), the multipliers were applied cumulatively. In other words, if a situation were such that two (or more) PSFs were applicable (negative influence on performance), the multipliers for the PSFs were applied consecutively in determining the final HEP.

Table F-1
Multipliers Used for increasing HEP values to reflect negative changes in conditions or poorer conditions

Change in PSF	Scoping Approach Multipliers
Fire effects ongoing (i.e., less than 70 minutes from the start of the fire)	10
Available time is less than or equal to 30 minutes	5
High execution complexity	5
Increases in smoke level (multiplier is applied for each of the two levels)	2
Decrease in time margin available	5

F.3.3 HEP Multipliers Across Flowcharts

The HEP values assigned for HFEs in which the diagnosis and execution of the action(s) takes place within the MCR are the minimum values obtainable (i.e., those values assigned through the use of the INCR flowchart depicted in Figure 5-3). The HEP values assigned when using the other flowcharts (i.e., execution takes place locally, HFE for alternate shutdown, or HFE for action[s] in response to an error due to spurious indicators) reflect assumptions about increasing difficulty resulting from those changes in conditions. Multipliers are used to reflect the changes in conditions addressed by the different flowcharts and are accounted for in the HEP lookup tables in Section 5. For instance, the HEPs assigned in Figure 5-4 (EXCR) covering HFEs for actions executed locally are two times greater than those HEPs assigned for HFEs covering actions executed within the MCR (INCR, Figure 5-3). This multiplier is based on the assumption that actions executed within the MCR will be practiced more regularly, will be clearly outlined in

procedural guidance, and will be subject to fewer extraneous variables. Similarly, the HEPs assigned for the HFEs covering actions for alternate shutdown (ASD, Figure 5-5) are two times greater than the HEPs assigned for HFEs involving locally executed actions (EXCR, Figure 5-4). Note that HEP values for the ASD tree were calculated assuming that fire effects were ongoing, so they correspond with that branch of the EXCR flowchart. Finally, the HEPs for HFEs covering recovery actions in response to EOOs or EOCs due to spurious instrumentation (SPI, Figure 5-6) take into account the greater ambiguity created by spurious instrumentation as well as where the execution of the action takes place. If the recovery of the EOO or EOC is to be executed in the MCR, the HEP is five times greater than the normal HEPs for actions executed within the MCR (INCR, Figure 5-3). On the other hand, if the recovery of the EOC or EOO is to be executed locally, the HEP is five times greater than the HEPs assigned for locally executed actions (EXCR, Figure 5-4). Note that HEP values for the SPI tree were calculated assuming that fire effects were ongoing, so they correspond with those branches of the INCR and EXCR flowcharts. The multipliers applied to the flowcharts are listed in Table F-2.

Table F-2
Calculation of HEP values across scoping flowcharts

HEP in Base Flowchart	Multiplied by	Adjustment Value	Equals	HEP in Scoping Flowchart
INCR (Figure 5-3)	X	2	=	EXCR (Figure 5-4)
EXCR (Figure 5-4)	X	2	=	ASD (Figure 5-5)
INCR (Figure 5-3) for in-MCR actions EXCR (Figure 5-4) for ex-CR actions	X	5	=	SPI (Figure 5-6)

An example may help to illustrate the use of the multipliers. A scenario involving the same PSFs is presented for each of the flowcharts to demonstrate the application of the multipliers across the flowcharts. The PSFs for the illustrative scenario are as follows:

- Minimum PSF criteria have been met prior to entering the flowcharts.
- Procedures match the scenario, indicating a straightforward diagnostic situation.
- Procedures exist for executing the ex-CR action (when applicable).
- Fire effects are ongoing (i.e., <70 minutes since the start of the fire).
- The area is accessible, and there is no fire in the vicinity of the action.
- Available time is greater than 30 minutes.
- Execution complexity is low.
- There is no smoke present.
- Time margin is 75%.

If this situation represented an action to be diagnosed and executed within the MCR, the final HEP would be 0.05 (INCR27 from HEP Lookup Table J).[22] This same scenario represented as a local, ex-CR action would have an HEP of 0.1 (EXCR28 from HEP Lookup Table X), which is equal to a factor of two applied to the INCR HEP. Similarly, these same PSFs—when applied to an action for alternate shutdown—would result in an HEP of 0.2 (ASD16 from HEP Lookup Table AG), which is equal to two times the EXCR HEP. If this same situation represented a recovery of an EOO or EOC due to spurious instrumentation and was executed in the MCR, the HEP would be equal to 0.25 (SPI16 from HEP Lookup Table AO). This value is the same as the HEP for normal in-MCR actions multiplied by 5. Finally, if the recovery needs to be executed locally as an ex-CR action, the HEP would be equal to 0.5 (SPI28 from HEP Lookup Table AT), which is five times larger than the normal HEP for an ex-CR action.

F.4 References

1. "Criteria for Safety-Related Nuclear Plant Operator Actions: A Preliminary Assessment of Available Data," P. M. Haas and T. F. Bott, *Reliability Engineering*, Vol. 3, pp. 59–72.
2. U.S. Nuclear Regulatory Commission. NUREG-1852, *Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire*, October 2007.
3. 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*, The American Society of Mechanical Engineers, New York, NY, February 2009.
4. U.S. Nuclear Regulatory Commission. NUREG/CR-6850, EPRI 1011989, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*. September 2005.

   Note: When reference is made in this document to NUREG/CR-6850/EPRI 1011989, it is intended to incorporate the following as well:

   Supplement 1, *Fire Probabilistic Risk Assessment Methods Enhancements*. EPRI, Palo Alto, CA: September 2010. 1019259.
5. NFPA 805 Transition Pilot Plant FAQ-08-0050, Final, "Non Suppression Probability," September 14, 2009. Available from U.S. Nuclear Regulatory Commission, ADAMS Accession Number ML092190555. This table was included in NUREG/CR-6850 Supplement 1[4].
6. U.S. Nuclear Regulatory Commission. NUREG-1880, *ATHEANA User's Guide*, May 2007.
7. U.S. Nuclear Regulatory Commission. NUREG/CR-6883, *The SPAR-H Human Reliability Analysis Method*, August 2005.

[22] The HEP of 0.05 can be obtained either by referencing HEP Lookup Table J in Table 5-3 in Section 5.2.6 or by applying the multipliers discussed in Section F.3.2. For instance, beginning with the base value of 1E-3 and applying the multipliers of 10 for ongoing fire effects and 5 for decreased time margin results in a final HEP of 0.05 (= 0.001 * 10 * 5).

8. U.S. Nuclear Regulatory Commission. NURGE/CR-1278, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications (THERP)*, A. D. Swain and H. E. Guttman, August 1983.

9. U.S. Nuclear Regulatory Commission. NUREG/CR-4772, *Accident Sequence Evaluation Program Human Reliability Analysis Procedure*, February 1987.

10. "The Origins of the SPAR-H Method's Performance Shaping Factor Multipliers," R. L. Boring and H. S. Blackman, Joint 8th IEEE HFPP/13th HPRCT, 2007.