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EPRI/NRC-RES Fire Human Reliability Analysis Guidelines

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U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
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EPRI/NRC-RES Fire Human Reliability Analysis Guidelines

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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 - External Events" (IPEEE). This effort produced a Fire Risk Assessment methodology for operations at power that was used by the majority of U.S. nuclear power plants (NPPs) in support of the IPEEE program and 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 they required upgrades to support current requirements for risk-informed, performance-based (RI/PB) applications.

In 2001, EPRI and the USNRC's Office of Nuclear Regulatory Research (RES) 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 1011989), entitled "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 identification and inclusion of human failure events (HFEs) into the fire PRA (FPRA), and a methodology 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). However, NUREG/CR-6850 did not describe a methodology to develop best-estimate HEPs given the PSFs and the fire-related effects.

In 2007, EPRI and RES embarked on another cooperative project to develop explicit guidance for estimating HEPs for human failure events under fire generated conditions, building upon existing human reliability analysis (HRA) methods. This document provides a methodology and guidance for conducting a fire HRA. This process includes identification and definition of post-fire human failure events, qualitative analysis, quantification, recovery, dependency, and uncertainty. This document 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 fewer resources than a detailed HRA analysis. For detailed HRA quantification, guidance has been developed on how to apply existing methods to assess post-fire fire HEPs.

FOREWORD

Fire probabilistic risk assessment (PRA) methods were used in the Individual Plant Examinations of External Event (IPEEE) program to facilitate a nuclear power plant examination for vulnerabilities. However, in order to make refined, more 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 (USNRC) review guidance with respect to many regulatory activities such as the risk-informed, performance-based fire protection rulemaking (endorsing National Fire Protection Association Standard 805). In order to address the need for improved methods, in 2001, the NRC Office of Nuclear Regulatory Research (RES) and Electric Power Research Institute (EPRI) collaborated 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-art Fire PRA methodology.

The fire HRA guidance provided in NUREG/CR-6850, included: 1) the process for identification and inclusion of the fire-related human failure events (HFEs), 2) the methodology for assigning quantitative screening values to these HFEs, and 3) 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 1008239, recommends use of "detailed HRA methods" to address cases where best estimate HEPs are needed. However, detailed HRA methods do not provide fire specific HRA guidance to systematically address fire specific PSFs and related effects, but rely on judgment of the analyst(s) to select PSFs, to evaluate the fire effects, to define HFEs and to assess HEPs.

The NFPA 805 transition initiative has encouraged the development of additional guidance for performing HRA for fire probabilistic risk assessment (FPRA). This project builds upon what is documented in NUREG/CR-6850, Volume 2, Section 12, and addresses the development of human reliability analyses, which satisfy available standards. These Fire HRA guidelines were originally written to the December 2006 draft version of the Fire PRA Methodology standard, which ultimately became ANSI/ANS-58.23-2007 in November 2007. Some sections of the report also cite ASME RA-S-2000, "Standard for PRA for Nuclear Power Plant Applications," and its addenda, ASME RA-Sa-2003 and ASME RA-Sb-2005, as they relate to internal events PRA issues that apply to Fire PRA/HRA. It was decided to issue this version of the Fire HRA Guidelines for public review and comment rather than delay it further to resolve any inconsistencies between the draft and final versions of the ANS standard, or to review and incorporate information from the recently published ASME/ANS RA-Sa-2009, "Level 1 and Large Early Release Frequency (LERF) PRA Standard," which applies to at power internal events, internal fire events, and external events for operating reactors. The necessary reviews and revisions to reflect the latest standard will be addressed prior to issuing the final Fire HRA Guidelines.

This report is the third product of the collaboration between EPRI and RES and comes under the auspices of the "Memorandum of Understanding (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 transition to NFPA 805 and possibly in response to other regulatory issues such as multiple spurious operation (MSO) and operator manual actions (OMAs). 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 document may benefit from future improvements to better support industry-wide issues being addressed by fire PRAs.

This document does not constitute regulatory requirements. RES participation in this study does not constitute or imply regulatory approval of applications based upon this methodology.

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REPORT SUMMARY

In 2001, EPRI and Nuclear Regulatory Research (RES) 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 power plants. NUREG/CR-6850 developed high-level guidance on identifying and including human failure events (HFEs) into the fire PRA (FPRA) and a methodology 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 does not provide a methodology for developing best-estimate HEPs given the PSFs and the fire-related effects.

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

Background

This report is intended primarily for practitioners conducting a post-fire HRA to support an FPRA. Because fire HRA builds on the internal event 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, a familiarity with general plant operations including procedure usage, and an understanding of the internal events scenarios and FPRA 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 analysis.

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.

Objectives

- To develop the methodology and supporting guidelines for estimating HEPs for HFEs following fire-induced initiating events of an FPRA

Approach

The EPRI/NRC team decided on 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 NUREG/CR-6850 HRA screening values 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 and peer reviewed by a team of industry and NRC members. The scoping approach was tested at two commercial nuclear power plants, and the draft guidelines were modified, revised, and developed into the current document.

Results

This report reflects a state-of-the-art fire HRA approach. It provides fire HRA practitioners with specific guidance for each step of the HRA process, and relates the HRA process to the fire PRA development, which is typically performed in parallel. This report built on what is documented in NUREG/CR-6850 regarding HRA and addresses the development of HRAs that satisfy the ASME PRA Standard and requirements of the fire 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 determine human actions needed to prevent core damage or large early releases.

EPRI Perspective

This report describes advancements in the understanding of HRA methods as applied to fire PRA. This is an interim report developed based on a consensus process involving both EPRI and NRC Research and is being issued in support of public comment on a draft NUREG. The HRA methods described herein 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 guideline offers improved guidance for fire HRA in support of FPRAs and their risk-informed regulatory applications. It is anticipated both that further improvements will be identified through the public comment process and that additional applications of this method and guideline will provide input into the final FPRA human reliability analysis methods.

Keywords

Human reliability analysis (HRA)
Probabilistic risk assessment (PRA)
Fire

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LIST OF ACRONYMS

AC	Alternating Current
ACRS	Advisory Committee for Reactor Safeguards
AFW	Auxiliary Feedwater
ANS	American Nuclear Society
AOP	Abnormal Operating Procedure
AP	Abnormal Procedure
AR	Annunciator Response
ARP	Alarm Response Procedure
ASME	American Society for Mechanical Engineers
ATHEANA	A Technique for Human Event Analysis
ATWS	Anticipated Transient Without SCRAM
ATWT	Anticipated Transient Without Trip
BHEP	Basic HEP
BOPCO	Balance of Plant Control Operator
BWR	Boiling Water Reactor
CBDTM	Cause Based Decision Tree Method
CCDP	Conditional Core Damage Probability
CCF	Common Cause Failure
CCW	Component Cooling Water
CDF	Core Damage Frequency
CLERP	Conditional Large Early Release Probability
CO	Control Operator
COPS	Cold Overpressure Protection System
CR	Control Room aka Main Control Room
CS	Containment Spray

CVCS	Chemical and Volume Control System
DAS	Data Acquisition System
DEC	Digital Equipment Corporation
DF	Dependent Failure
DHR	Decay heat removal
ECA	Emergency Contingency Action
ECCS	Emergency Core Cooling Systems
EDG	Emergency Diesel Generator
ELOCA	Excessive LOCA
EOC	Error of Commission
EOM	Error of Omission aka EOO
EOP	Emergency Operating Procedure
EOO	Error of Omission aka EOM
EP	Emergency Plan
EPRI	Electric Power Research Institute
ERF	Emergency Response Facility
ESW	Essential Service Water Cooling System
ET	Event Tree
EOF	Emergency Operations Facility
FPC	Fuel Pool Cooling
FPRA	Fire PRA
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
HR	High Pressure Injection
HRA	Human Reliability Analysis

HVAC	Heating, Ventilating, and Air Conditioning
ICCDP	Incremental Conditional Core Damage Probability
ICLERP	Incremental Conditional Large Early Release Probability
IE	Initiating Event
IEF	Initiating Event Frequency
ILRT	Integrated Leak Rate Test
IPE	Individual Plant Examination
IPEEE	Individual Plant Examination of External Events
IRT	Independent Review Team
ISL	Interfacing Systems LOCA
ISLOCA	Interfacing Systems LOCA
JPM	Job Performance Measure
LB	Lower Bound
LER	Licensee Event Report
LERF	Large, Early Release Frequency
LLOCA	Large LOCA
LOCA	Loss of Coolant Accident
LOSP	Loss of Offsite Power
LPI	Low Pressure Injection
LPSD	Low Power and/or Shutdown
LPSI	Low Pressure Safety Injection from RWST
LPSR	Low Pressure Sump Recirculation
LTOP	Low Temperature Overpressurization
LWR	Light Water Reactor
MCCB	Motor-Controlled Circuit Breaker
MCR	Main Control Room aka Control Room
MLOCA	Medium Loss of Coolant Accident
MLT	Mean-Logistics-Time
Mode	Technical Specification Operating Mode
MRT	Mean-Repair-Time
MSLBIC	Main Steamline Break Inside Containment
MSLBOC	Main Steamline Break Outside Containment
MSO	Multiple Spurious Operations

MTBF	Mean-Time-Between Failure
NFPA	National Fire Protection Association
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NSS	Nuclear Steam Supply System
NUREG	Nuclear Regulatory Commission Document
OA	Operator Action also called Human Interaction
OMA	Operator Manual Action (typically in response to a fire) - In Appendix R these are local manual actions (outside of the MCR) - In fire PRA these may be operator actions added in response to a fire, such as to mitigate spurious indications or alarms.
OP	Operating Procedure
OSC	Operations Support Center
PM	Project Manager
PORV	Power Operated Relief Valve
POS	Plant Operational State or Plant Operating State
PRA	Probabilistic Risk Assessment (aka PSA)
PSA	Probabilistic Safety Assessment (aka PRA)
PSF	Performance Shaping Factor
PTS	Pressurized Thermal Shock
PWR	Pressurized Water Reactor
RAW	Risk Achievement Worth
RCS	Reactor Coolant System
RES	U.S. NRC Office of Research
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
S/G	Steam Generator
SCBA	Self-Contained Breathing Apparatus
SD	Shutdown

SDP	Significance Determination Process
SF	Shift Foreman
SG	Steam Generator
SGTR	SG Tube Rupture
SISBO	Self-Induced Station Blackout
SI	Safety Injection
SLOCA	Small Loss of Coolant Accident
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
WOG	Westinghouse Owners Group, now the PWR-OG

1
INTRODUCTION

1.1 Background

Over the past two decades the nuclear power fire protection community in the United States and overseas has been transitioning towards risk-informed and performance-based (RI/PB) practice in design, operation and regulation.

Under a joint Memorandum of Understanding (MOU), the Electric Power Research Institute (EPRI) and the USNRC Office of Research (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, entitled "Fire PRA Methodology for Nuclear Power Facilities" [1] which addresses fire risk for at-power operations. For the human reliability analysis task, NUREG/CR-6580 developed the following.

1. Process for identification and inclusion of the human failure events (HFEs)
2. Methodology for assigning quantitative screening values to these HFEs, and
3. 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 did not identify or produce a methodology to develop these best-estimate HEPs given the PSFs and the fire-related effects.

The USNRC Office of Research and EPRI fire research cooperative program also produced NUREG-1824 & EPRI 1011999, "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications," in May 2007 [2].

1.2 Programmatic Overview

This report is the third product of the collaboration between EPRI and the USNRC Office of Research and comes under the auspices of the "Memorandum of Understanding (MOU) 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 transition to NFPA 805 and possibly in response to other regulatory issues such as multiple spurious operation (MSO) and operator manual actions (OMAs). This is the first report addressing post-fire human reliability analysis for fire PRAs that goes beyond the screening level. As the methodology is applied at a wide variety of plants, the document may benefit from future improvements to more fully support industry-wide issues being addressed by fire PRAs.

1.2.1 Objectives

The objective of this report is to develop the methodology and supporting guidelines for estimating human error probabilities (HEPs) for human failure events following fire-induced initiating events of a probabilistic risk assessment (PRA). This report builds upon existing human reliability analysis (HRA) information such as HRA process and HRA methods, and the screening method included in NUREG/CR-6850. 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].

1.2.2 Project Tasks

The post-fire HRA methodology and supporting guidelines were developed using a structured, systematic approach. The approach consisted of the following three primary tasks, each of which has one or more supporting tasks as described in the text below.

1. Fire Data Review
2. Fire HRA Methodology and Guideline Development
3. Fire HRA Review and Testing

1.2.2.1 Fire Data Review

The first task consisted of a review of fire PRA requirements and historical fire data to better understand what is currently required in a quality fire PRA, and what is known about the effects of fire on human reliability and human performance from historical experience.

The first sub-task was to conduct a review of the requirements of a quality fire PRA as prescribed in the fire PRA standard [3]. The insights associated with this review are documented in Appendix A. A fire PRA developed following the guidelines in NUREG/CR-6850 and the requirements of the fire PRA standard must address undesired response to spurious signals such as instrumentation or component actuation, and this requirement is addressed in this report.

Additionally, recent historical data from actual fire events was reviewed, as summarized in Appendix B, in order to determine if additional failure modes or performance shaping factors would need to be considered for fire scenarios beyond those already identified in NUREG/CR-6850. This task built upon previous, unpublished work conducted by Sandia Laboratories and the NRC. The results of this review are documented in Appendix B. Additionally, in this phase, EPRI conducted operator interviews and collected fire response procedures from PWR and BWR reactors to more fully understand the fire protection philosophy and the intended use of fire procedures in conjunction with normal emergency operating procedures during post-fire plant response.

1.2.2.2 Fire HRA Development

The fire HRA development task used the insights from the fire data review as well as insights into human reliability analysis methods, based on NRC and industry experience. Insights from the development of NRC documents evaluating the current state-of-the-art in human reliability such as the "Good Practices for Implementing Human Reliability Analysis" [4] and "Evaluation of Human Reliability Analysis Methods Against Good Practices" [5] were complemented with insights gained by EPRI in the development of HRA methods [6] and applying these methods using PRA standards [3, 7]. The insights from these reviews identified the following sub-tasks to be addressed in developing a post-fire human reliability analysis.

1. Define the process steps (listed below) that represent the framework for developing a post-fire human reliability analysis.
    a. Identification and Definition
    b. Qualitative analysis (context and performance shaping factors)
    c. Quantification:
        i. Screening quantification (update of NUREG/CR-6850 screening)
        ii. Scoping quantification (new approach developed for fire HRA)
        iii. Detailed quantification (applying the EPRI HRA approach and/or ATHEANA)
    d. Recovery analysis
    e. Dependency analysis
    f. Uncertainty analysis
    g. Documentation
2. Develop methods to conduct the steps in the fire HRA process.
3. Develop guidelines associated with the fire HRA methodology.

1.2.2.3 Fire HRA Testing Tasks

The testing phase included an independent peer review, application testing, internal review by NRC and EPRI (in addition to the project team), a public comment period, and review by the Advisory Committee for Reactor Safeguards (ACRS) prior to its publication. The independent peer review and application testing sub-tasks are summarized below.

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) comprised of experts in the subject areas of HRA, PRA and/or fire. The specific mission of the IRT was to:

- Check the validity of the method and technical bases
- Check the detail and clarity of the guidance to ensure consistent and accurate application of the guidance.

The independent review team was comprised of the following individuals:

Dr. Gareth Parry, U.S. NRC
Dr. Erasmia Lois, U.S. NRC
Dr. J.S. Hyslop, U.S. NRC
Dr. Zouhair Elawar, Arizona Public Service
Ken Kiper, Florida Power and Light Company
Dr. Young Jo, Southern Nuclear Operating Company
Stuart Lewis, Polestar Applied Technology, Inc.

Testing. Portions of the fire HRA guidance developed in this document were tested through application as part of on-going fire PRAs by the development team and by an owner's group team that is independent of the developers. The objectives of the testing were to ensure that: a) the method is robust and applies to all types of plants and the range of post-fire operator actions expected to be needed in a fire PRA, b) there is sufficient and clear guidance for the users to render consistent application, and c) the guidance produces reasonable best-estimate values for human error probabilities.

While the specific scope of the testing depends on the volunteer plants and the status of their fire PRA, the testing was intended to exercise the following portions of the fire HRA methodology guidelines:

1. Identification and definition of HFEs primarily through review of this guidance against work done as part of the fire PRA.
2. Quantitative Screening and Scoping HRA Quantification for a selected set of HFEs. The set was selected to address technical issues and capture performance shaping factors (PSFs) to the extent possible.

The results of the testing and the peer review have been documented in Appendix F of this document, including the insights gained.

1.3 Scope

This document describes the process and technical bases for the performance of the human reliability analysis as part of a fire PRA. This document 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). It is intended to be a stand alone reference which supplements and extends the guidance in NUREG/CR-6850 [1] 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 FPRA model. The scope of the fire HRA focuses on post-initiating event (dynamic) human failure events, and these are grouped into the following categories:

- Existing Internal Events HFEs – actions from the internal events PRA that are used
- Fire Response HFEs – including Main Control Room Abandonment HFEs (which are considered as a special sub-set of the fire response HFEs)
- HFEs corresponding to undesired response to spurious actuation or spurious instrumentation

Pre-Initiating Event (Latent) HFEs. Latent human failure events are not addressed in this document. All existing pre-initiators in the Level 1, Internal Events PRA model are independent of the initiator and, hence, independent of a fire initiator as well. The existing pre-initiators do not need to be re-analyzed, but should be retained in the FPRA model as their impacts remain relevant to the conditional core damage probability (CCDP) and conditional large early release probability (CLERP). NUREG/CR-6850 [1] states that:

> "…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…"

Thus, 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, then latent HFEs would be added using standard HRA modeling techniques. It should be noted that NUREG-1792, Good Practices in HRA, [4] documents that it is a good practice to review historical data for fire dampers. The multi-compartment analysis portion of the fire PRA may consider mis-positioned fire dampers, but there is no difference from the standard HRA methods for identification, qualitative and quantitative assessment and thus latent HFEs are not addressed in this report.

Fire Detection HFEs. 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; and in other areas, the frequency of the roving fire watch is considered to determine detection probability.

Fire Suppression HFEs. NUREG/CR-6850 [1] uses a statistical evaluation of historical events to assign reliability estimates for the fire suppression systems. Suppression is modeled by a set of curves showing probability of non-suppression as function of time available for suppression; there are curves for various types of fires and locations within a NPP. Since 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 human reliability analysis task. The NUREG/CR-6850 non-suppression curves are based on historical data for automatically actuated suppression systems. Human failure events modeling manual actuation of suppression systems would be accomplished following the guidance of this report.

Performance Shaping Factors. Many, if not all, of the fire impact on the human reliability analysis comes through the influence on performance shaping factors such as cues, procedures, and timing. Additionally, the impact of interactions among the fire brigade and the operational crew may be considered in PSFs such as increased workload or staffing, and are within the scope of the fire HRA methods in this report.

1.4 Intended Audience and Prerequisite Expertise

This document is aimed primarily at human reliability analysts involved in Nuclear Power Plants (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 document 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.

HRA involves qualitative and quantitative analysis of plant-specific, fire safe shutdown operator actions. Hence, 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 the 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 multi-disciplinary team will benefit by including deterministic fire modeling experts to describe the fire ignition and progression modeling, and electrical expertise to describe the fire impact on electrical circuits including open circuits and/or hot shorts. The HRA expert should assist the PRA analyst to identify and appropriately incorporate human actions in the plant fire safe shutdown response model.

1.5 Report Structure

This report is structured in the following sections and associated Appendices.

Section 1 delineates the objectives and scope of this report, as well as providing the background information on the project tasks conducted in developing the fire HRA methodology and guidelines.

Section 2 provides an overview of the guidance provided in the report. It is intended to show to the user various steps in conducting fire HRA and how these steps may fit into a fire PRA.

Section 3 describes the guidance for identifying actions and defining human error events that are to be considered, and guidance on how to model in a fire PRA. This is a revision of the guidance provided in NUREG/CR-6850, Volume 2, Section 12.5.1 [1].

Section 4 describes the qualitative attributes contributing to quantification of HFEs including performance shaping factors. This is a revision of the guidance provided in NUREG/CR-6850, Volume 2, Section 12.5.5 [1].

Section 5 describes the post-fire HRA quantification. Three approaches to quantification are offered. 1) screening, 2) scoping, and 3) 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 [1]. Scoping is a more refined quantification than Screening HRA (Section 4 of this report) but less refined than a detailed fire HRA. Detailed HRA is the application of either the EPRI HRA approach or ATHEANA.

Section 6 describes the process for identifying defining and quantifying recovery actions. The types of recovery actions considered in Section 6 are those that were not added to the fault trees and event trees as part of the planned plant response. Instead, they are actions that are added at the sequence or cutset level to re-align the affected system, or to provide an alternate system, such that success of these actions would have prevented core damage and/or large early release.

Section 7 describes the process for how to assess dependencies.

Section 8 describes the guidance for conducting the uncertainty evaluation.

Section 9 describes an overview for what to include in the documentation.

Appendix A offers an examination of fire HRA analyses based on this guidance against the requirements of the fire PRA Standard [3].

Appendix B provides a limited review of recent operating experience in the U.S. nuclear power industry geared towards gaining insights on operator behavior during historical fire events.

Appendices C and D provide guidance for detailed quantification of HFEs using EPRI HRA Cause-Based Decision Tree (CBDT) and Human Cognitive Reliability/Operator Reliability Experiments (HCR/ORE) methods, and the ATHEANA method, respectively.

Appendix E contains the definition of terms used in this report.

Appendix F contains a summary of the testing, including scope and insights.

Appendix G contains guidance on how to identify and define HFEs for fire-related electrical bus clearing and restoration procedures.

Appendix H provides the justification for the scoping human error probabilities.

1.6 References

1. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities.* September 2005. NUREG/CR-6850/EPRI 1011989.
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2
FIRE HRA FRAMEWORK

2.1 Introduction

The NFPA 805 transition initiative has encouraged the development of guidance for performing human reliability analysis (HRA) for fire probabilistic risk assessment (FPRA). This project builds upon what is documented in NUREG/CR-6850, Volume 2, Section 12 [1] and addresses the development of human reliability analyses satisfying both the ASME PRA Standard [2] and current requirements of the fire 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 prevent core damage or large early releases.

2.2 Fire HRA Process

To model a fire HRA, NUREG/CR-6850 [1] recommends the process listed below and shown in Figure 2-1. This conceptual approach is based upon the SHARP1 framework for HRA [4], the approach used in ATHEANA [5], and the approach outlined in the ASME PRA Standard, [2] on which the Good Practices for Implementing Human Reliability Analysis [6] are based.

The following comprises the fire HRA process. Figure 2-1 shows the relationship to other HRA methods and tasks. The subsequent text summarizes the changes in this document from the original NUREG/CR-6850 HRA development.

1. Identify and define HFEs
    - Internal events HFEs
    - Fire response HFEs
    - HFEs corresponding to undesired operator responses to spurious actuation or spurious instrumentation
    - Main control room abandonment HFEs
    - Initial assessment of the feasibility of the HFE
2. Qualitative evaluation
    - Develop narrative describing the initial conditions and the context for the HFE
    - Assess performance shaping factors
    - Operator interviews
    - Experience review

3. Quantitative evaluation of the human error probability (HEP) using one of the following:
    - Screening approach
    - Scoping approach to quantification
    - Detailed approach to quantification
4. Recovery
    - Identify and define
    - Quantify
5. Dependency evaluation
    - Identify combinations of multiple operator actions
    - Evaluate dependencies
    - Incorporate dependency evaluation into the fire PRA model
6. Uncertainty analysis
7. Documentation

Identification and Definition. The identification and definition process is largely unchanged from NUREG/CR-6850.

Qualitative Evaluation. For fire HRA, a qualitative analysis step (Section 4) has been added as a stand-alone step. In many methods, this step is implicitly considered in the identification and definition step. This step has proven to be important in the recent benchmarking exercise of HRA predictions with empirical data, and thus is described explicitly.

Quantitative Evaluation. 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 the methods. If the analyst finds the screening and scoping methods to be too conservative or limiting, then he or she is encouraged to use one of the more detailed HRA methods.

The screening methodology (Section 5) assigns quantitative screening values to the HFEs modeled in the fire PRA by addressing the unique conditions created by fires. In those instances where a less conservative analysis is required (i.e., conservative screening values are unacceptable), the next stage presented is a scoping analysis. The scoping analysis (Section 5) 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, and a good understanding of the many performance shaping factors (PSFs) likely to influence the behavior of the operators in the fire scenario. It is likely that some actions will not be able to meet the criteria for the scoping HRA method, due to any number of reasons. For such cases, a detailed HRA approach is required.

Recovery, Dependency and Uncertainty. These are aspects of the fire HRA that were not addressed in NUREG/CR-6850.

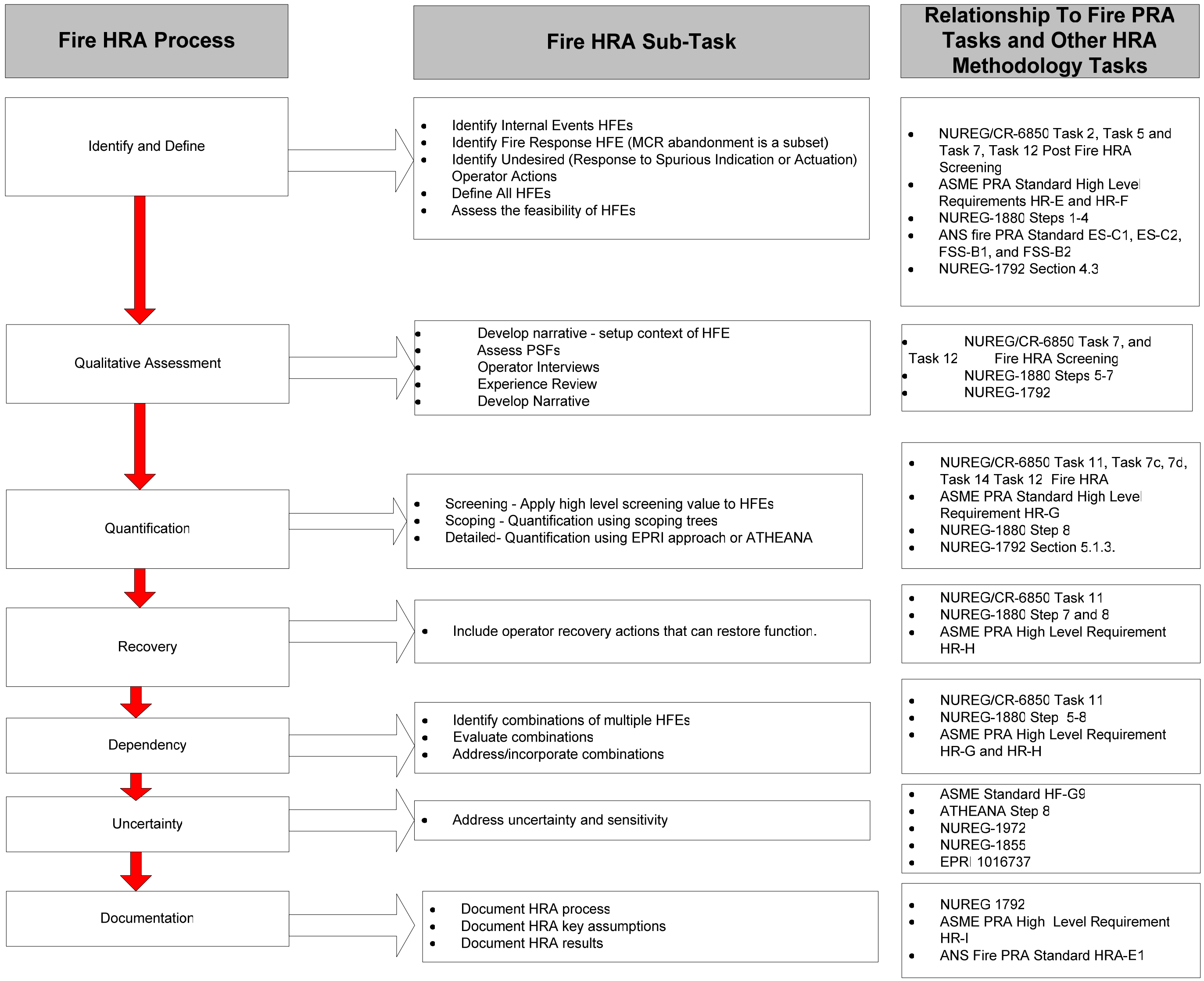

Figure 2-1
Fire HRA process

2.3 Relationship to Other Fire PRA Tasks

Fire HRA is an iterative process and is developed in conjunction with a fire PRA. It 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 [1]. Similarly, the fire HRA output feeds several NUREG/CR-6850 fire PRA tasks, including various levels of fire PRA quantification (for example, 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 [1], and these lines represent either the end results or the inputs to the fire HRA (Task 12). The dotted lines have been added for completeness and the information is not necessarily considered as an input or end result per NUREG/CR- 6850 [1]. For example, the timing information necessary for the HEP quantification will come from an intermediate step of Task 8 but is not explicitly identified as an output of Task 8. NUREG/CR-6850 [1] 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 since identified human actions may imply additional equipment and diagnostic indications, which need additional human actions. Note that the equipment and indications will involve (1) those needed for potential success of actions required by EOPs, fire procedures, and (2) those whose failure (including spurious events) during a fire can influence operators to isolate or to reposition critical equipment into a less desirable position.
- NUREG/CR-6850 Task 5, Fire-Induced Risk Model, will provide a list of human actions already included as basic events in the portions of the Internal Events PRA that are 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 (HEPs) 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 CDFs and/or 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 HEPs. 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 so as 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 has proven to be useful in defining scenario-specific factors affecting HRA. These factors impact the quantification of screening HEPs, as well as scoping and best-estimate quantification of the more important HEPs. 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 so as 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 HEPs, are inputs into the final risk quantification performed under NUREG/CR-6850 Task 14, Fire Risk Quantification."

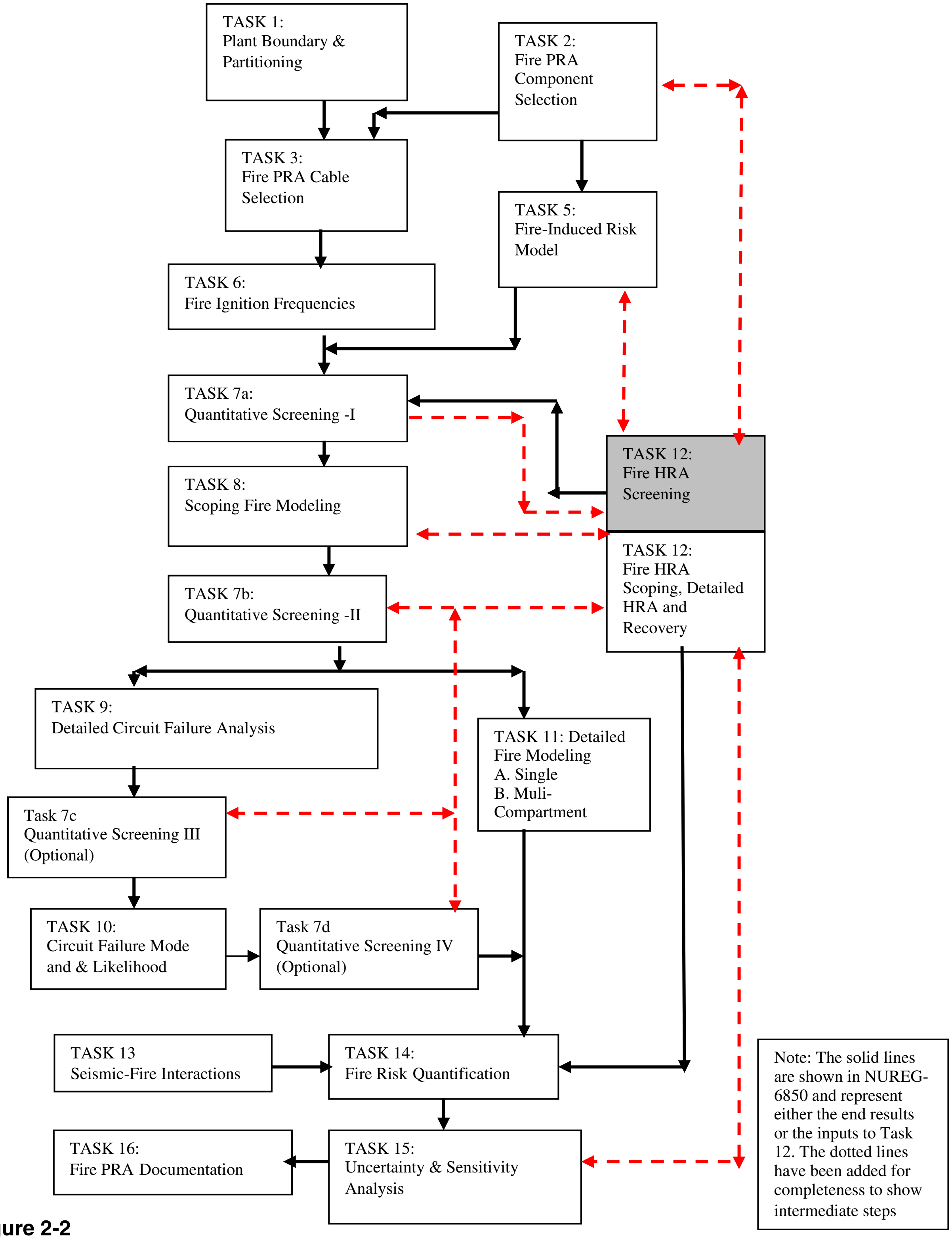

Figure 2-2
Mapping of fire HRA task 12 to NUREG/CR-6850 [1] PRA tasks[1]

[1] Note: Task 7c and 7d added to figure based on discussion in NUREG/CR-6850.

2.4 General Assumptions

The work performed under these guidelines assumes the following:

1. The FPRA and fire HRA are only concerned with fires that cause an initiating event, which 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 [1]:
   - 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. Thus 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 program” or from NFPA-805 safe shutdown analysis, are proceduralized in the plant fire response procedures. It is not within the scope of this document to identify new “Appendix R” or NFPA-805 safe shutdown actions required to satisfy the plant’s fire protection program requirements. This document has addressed identification of operator actions required for fire PRA and these actions may or may not be added to the Appendix R/NFPA-805 safe shutdown list. 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, 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 their workload, among others.
3. As stated above, it is assumed that the crew is aware of the fire location within a short period of time (~10 minutes). Once the crew is aware of the location, the fire brigade will work quickly to extinguish the fire. For HFEs where there are several hours available after reactor trip to perform the action, it is assumed that the action is time independent of the fire, and fire impacts will have very little if any effect on the operator performance.
4. The objective of the Main Control Room 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 Technical Bases

The fire HRA Methodology has been developed within the framework of, and uses to the extent practicable, existing HRA methods that are currently 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 the fire conditions when the screening and scoping approaches are not adequate. While there are many HRA methods available, this project focused on two cognitive/execution methods to perform detailed HRA for fire context. Neither is it the objective of this project to research performance shaping factors (PSFs) and screening human error probabilities beyond what is documented in Volume 2, Section 12 of NUREG/CR-6850 [1]. These PSFs are similar to and consistent with the ones derived by the NRC (defined as manual actions feasibility criteria) in NUREG-1852 [7]. Lessons learned from this process can then be applied to other HRA methods on an as-needed basis.

- **EPRI HRA Methodology – CBDT [7] and THERP [9]:** Recent industry efforts have focused on a standardized approach using the EPRI Cause-Based Decision Tree method (CBDT) [8, 10, and 11] for the cognitive aspect of HRA including detection, diagnosis, and decision-making. CBDT [8] is complemented by the EPRI HCR/ORE [10] for modeling cognition of time-sensitive actions. THERP [9] is used to model the execution/manipulation aspect of the HRA. This collective set of CBDT, HCR/ORE, and THERP is referred to as the EPRI HRA approach in this report.
- **ATHEANA [5]:** The USNRC's ATHEANA method appears to be suitable for a fire HRA because it offers a structured process for identifying critical aspects of successes/failures associated with abnormal operations. Also, ATHEANA is not limited to a specific set of performance shaping factors (PSFs) or plant conditions, allowing fire-specific PSFs and contexts to be easily accommodated.

In addition to the above 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 upon the principles and concepts embedded in the ATHEANA and EPRI HRA methods, plus other related HRA information (e.g., concepts of "feasibility" and "time margin" that were introduced in NUREG-1852 [7]).

2.6 References

1. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities.* September 2005. NUREG/CR-6850/EPRI 1011989.
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3
IDENTIFICATION AND DEFINITION

3.1 Introduction

The objectives of the identification and definition task are to (1) identify operator actions and associated instrumentation that are necessary for successful mitigation of fire scenarios, and (2) to define the human failure events (HFEs) at the appropriate level of detail necessary to perform NUREG/CR-6850 [1] tasks up to initial risk model development (in Task 5). A detailed definition is needed for the qualitative HRA in Task 12.

It is intended that the identification and definition task be performed early in the FPRA 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, and the identification of actions can be helpful for risk modeling in Task 5. As the initial risk model is developed, the FPRA analysts will need to develop which operator actions can or can not be credited.

As in the internal events HRA, operator actions are primarily identified by accident sequence and procedure review. Identification of post-initiators 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 those procedures which 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 review of EOPs and associated event trees. ARPs are those procedures to which the operators are directed in response to an annunciator.

Fire procedures are procedures (beyond the normal EOPs/AOPs) that the operators will use in response to a fire. Currently, in the United States, there is no standardized fire procedure or format among plants. Fire procedures have historically been developed to meet 10CFR50 Appendix R[1] requirements, but many utilities are transitioning their fire protection program to one based on the National Fire Protection Associations risk-informed, performance-based program called NFPA-805. A plant may have one fire procedure or many fire procedures depending on their 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 co-mingled.

[1] Within the context of Fire PRA Chapter 10 Appendix R of the Code of Federal Register is commonly referred to as Appendix R and this short hand many be used through out this report.

The naming of fire procedures can also vary among plants: common names include fire procedures, pre-fire plans, fire strategies, serious station fire procedure, main control room abandonment procedures, site emergency response procedure (which include a section for fire). NUREG/CR-6850 [1] refers to all these procedures as fire emergency procedures (FEPs). Throughout this document, the term fire procedure will be used to reference to any type of procedure (beyond the normal EOPs/AOPs) that the operators will use in response to a fire. For fire HRA there are 3 types of post-initiator operator actions to consider:

- Internal events operator actions.
- Fire response operator actions – main control room abandonment actions are considered as a special sub-set of the fire response operator actions.
- Undesired operator responses to spurious actuation or spurious instrumentation.

The identification of fire response actions includes the following actions that may be required in the FPRA model:

- Fire response actions to mitigate the expected fire damage, by providing mitigation using equipment taken credit for in Task 2 of the FPRA.
- Pre-emptive fire response actions to prevent fire damage to equipment (protect equipment) needed in the FPRA.
- Fire response actions recovering PRA sequences or cutsets, typically consisting of multiple equipment failures and/or failed operator action(s).
- Fire response actions to mitigate spurious indications and actuations.

3.2 Internal Events Operator Actions

Internal events operator actions are actions that are required in response to a reactor trip and/or safety injection, typically directed by the emergency operating procedures (EOPs), alarm response procedures (ARPs), abnormal operating procedures (AOPs) and/ or normal operating procedures (NOPs).

Internal events operator actions are identified by considering the fire-induced initiating events and their related fault and event trees from the internal events PRA. Since these operator actions had already been identified, their HFEs defined, and their human error probabilities (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 FPRA identification process is to determine which of these HFEs could occur in fire scenarios. This is accomplished by (1) identifying the fire-induced initiating events from NUREG/CR-6850 [1] Task 2; and (2) identifying 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 the HFEs that are 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" – the implied operator action is therefore "start auxiliary feedwater."

Existing internal events HFEs that are 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 need not be considered in the fire PRA.

For fire HRA, there are potentially two sub-types 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 or are developed into detailed HEPs (instead they are typically set to conservative screening values in the internal events PRA). The second type of action is identified by the same process as for actions already included in the internal events PRA. The only difference is once the qualitative analysis stage is reached, the HRA analyst will not have a base analysis from which to work. To ensure the identification task is complete, the following steps are all required, but not necessarily in the following order. The point at which each of the steps is completed will depend on the development of the fire PRA. The following steps are a summary of the discussion presented above.

Step 1) Identify all operator actions in 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 initiators are separated. All existing pre-initiators in the Level 1, internal events PRA model are independent of the initiator and hence independent of a fire initiator as well. The existing pre-initiators do not need to be re-analyzed, but should be retained as-is in the FPRA model since their impacts remain relevant to the CCDP and CLERP.

Step 2) Screen from consideration internal events HFEs that are not associated with fire-induced initiating events. These initiating events are identified in Task 2 of NUREG/CR-6580 [1]. Examples of initiators not typically included in fire PRA are large LOCA and ATWS (for BWRs and PWRs), and SGTR (for PWRs). There may be cases were a single HFE analysis is used for several initiators and the limiting case initiator is not associated with the fire PRA. In these cases, the HFE should not be screened from consideration but should be re-evaluated from first principles to correctly model the fire impacts. For example, the timing of an HFE maybe 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 re-evaluated in the qualitative analysis.

Step 3) Review fire related fault trees and event trees. ASME 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 (b) system operation such that an understanding of how the system(s) functions and the human interfaces with the system is obtained*". For this identification step, it is important that the internal events HRA meets ASME category II and a review of plant procedures had already been completed for the internal events model. This fire HRA guideline has been written assuming the internal events PRA model is up to date and meets Capability Category II of the PRA Standard. However, it is necessary to review the fire fault trees and events trees 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 actions are proceduralized actions in the EOP and/or AOP/ARP/NOPs that were not considered important for the internal events model due to a low probability of associated component failure. An example of this type of action is manual back-up 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, but in a post-fire situation the hardware could be failed by the fire, or its reliability severely degraded, such that manual operator actions are needed and must 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 which will be re-visited as the fire PRA model develops.

Step 4) Define each internal events HFE

The definition of existing internal events HFEs must be revised for fire impact. All the assumptions and inputs that are used in the internal events HFE analysis must be systematically considered for fire impact including:

- Fire impact on instrumentation and indications credited for detection and diagnosis.
- Fire impact on timing of cues, response, execution, and time available.
- Fire impact on success criteria.
- Fire impact on manpower resources, which affect recovery.
- Fire impact on local actions, e.g., accessibility, atmosphere, lighting.

Further discussion on how and what to consider in the definition of the HFE is presented in Section 4. The identification and definition is an iterative process and is added here for completeness for the reader.

3.3 Fire Response Operator Action Categorization

Fire response operator actions are new post-initiator operator actions required in response to a fire. They are typically directed by the fire procedure(s). They are sometimes called fire manual actions and are referred to elsewhere in this document simply 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 function in the fire PRA.

3.3.1 Fire Response Actions to Mitigate the Expected Consequences of Fire Damaged Equipment Needed in the FPRA

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/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 this information may change as the modeling progresses, for example from a complete loss of instrumentation in the first quantification of NUREG/CR-6850 Task 7 [1] to a partial loss of instrumentation in a more detailed quantification of the same area in NUREG/CR-6850 Task 11 [1]. 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.

Examples of fire response human failure events (HFEs) are listed below. Note that each of these HFEs may require several sub-task failures to be modeled or some of these HFEs may be later consolidated into one HFE. Such subdivision or consolidation would depend on the level at which the HFE is required in the logic model e.g. function, system, train or component level would require different levels of resolution.

- 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 main control room 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 motor the control circuit is failed by the fire.
- Operators fail to restore steam generator level by locally controlling auxiliary feedwater after fire damages control room indicators.
- Operators fail to isolate pressure operated relief valve (PORV) after it spuriously opens during the fire and cannot be closed from the control room.

The fire HRA should not take credit for any fire response actions that are not proceduralized except as described in Section 6.

3.3.2 Pre-Emptive Fire Response Actions to Prevent Fire Damage to Equipment (Protect Equipment) Needed in the FPRA

Most pre-emptive fire response HFEs involve failures to de-energize power supplies or disable control systems in order to prevent spurious actuations. Some examples are shown below.

- Operators disable a solid state protection system.
- Operators de-energize a motor control center.
- Operators de-energize pressurizer heaters.

These actions are explicitly stated in the fire procedures; however, they 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 pre-emptive measure in order to mitigate any spurious actuations. Detailed guidance for SISBO plants is described in Appendix G. These pre-emptive actions can be identified and HFEs defined and modeled before screening (see Section 5), or after initial quantification, and as needed, from the initial fire PRA results.

3.3.3 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/wish to credit an additional action. This action could be one 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 but, 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) and the potential success path to be applied needs to be known. The latter is often identified as a result of operator interviews. Given that the existing internal events actions

applicable to the FPRA have been identified, the fire impact on them due to 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). As noted above, the fire impact is first quantified in the fire modeling tasks of Task 7, and later refined in Task 11.

3.3.4 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 for fire response actions, but the procedure review would be limited to the fire procedures that apply to MCR abandonment and establishment of local control. Local control may be at a one or more local control panels, breakers, or pieces of equipment. In addition to the local fire response actions, the cognitive decision for MCR abandonment needs to be addressed. Generally there are two criteria for MCR abandonment, either due to uninhabitability or inability to control the plant. The criteria used in the fire PRA model for MCR abandonment or use of alternative shutdown needs to be defined. The decision to abandon the MCR is an area of uncertainty since there may not always be clear 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, for example due to fire effects on control cables.

In the initial stages of the FPRA development, the decision for abandonment will be determined by the fire PRA analyst as a simple “yes” (MCR abandonment is required) or “no” (MCR abandonment is not required). If the fire PRA determines that the operators will abandon the control room then it is the HRA analyst’s task to identify the operator actions required for success (based on review of the MCR abandonment procedure) once 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 FPRA analyst will need to define the operator actions required for success on a scenario specific basis.

3.3.5 Manual Actuation of Fixed Fire Suppression Systems

Manual actuation of fixed fire suppression systems are included in the HRA scope of this report. 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. Since the fire suppression probability is addressed with data, it is not necessary for the HRA to model the fire brigade response.

However, manual actuation of automatic fire suppression systems from the control room during an event is within the scope of the HRA since it is not accounted for in the non-suppression probability curves. These actions are identified in 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.

3.4 Fire Response Operator 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 FPRA. In order to understand what fire response actions are required in the FPRA, it is necessary to first understand the fire scenarios, which requires modeling of the fire impacts on equipment and instrumentation in the FPRA. However, if the FPRA modeling has not advanced to this stage yet, *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 FPRA. An iterative approach using three steps is followed in order to identify fire response actions.

Step 1) Develop fire scenarios first to understand the impact of fire on equipment and instrumentation, and then identify specific fire response actions required for mitigation. For this approach, ideally, the fire FPRA has developed past NUREG 6850 Task 5 risk model development. The HRA analyst and fire PRA analyst will work together to review the fire scenarios in conjunction with both 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 timeline for the fire sequence of events in sufficient level of detail such that the HRA analyst can map the expected operator action as directed in the fire procedures to the specific fire sequence. This many also require operator interviews to confirm the expected plant response for each fire scenario.

Step 2) Identify *all* procedural fire response actions, and then apply only those that are required for mitigation once the fire impacts on equipment and instrumentation becomes 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 below:

Fire Response Basic Event Identifier	Related Basic Event Identifier in PRA	Equipment	Fire Response Basic Event Description
ACP-OPS-ISO-1F1A	None	4160V Bus 1F	Operators fail to isolate 4160V Bus 1F from Bus 1A
ACP-OPS-ISO-1FDG1	EAC-OPS-FO-DG1 – Operators fail to operator Diesel Generator 1 (DG 1)	DG1	Operators fail to align DG1 to 4160V Bus 1F by isolating and operating DG1 and Breaker EG1 per 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 per 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 per section 9 of procedure 5.4.30.1
FZ50-OPS-SUPRESS	None	Fire suppression system FZ AA-55	Operators fail to active suppression system for AA-55 from control room
AFW-OPS-XTIE-FIRE	AFW-OPS-XTIE – Operators fail to cross tie Auxiliary Feedwater (AFW) per AOPs	AFW FM-124	Operators fail to cross-tie AFW per the Main Control Room abandonment procedure

This approach is resource intensive for the HRA analyst but does provide clear documentation of the procedure review in order to meet ASME standard requirements HR-E1 and HR-E2. This approach also provides the fire PRA analyst with all possible actions that can be credited and the fire PRA analyst can implement these actions on an as needed bases.

Step 3) An iterative approach combining the above two approaches. Since the fire HRA task is typically not performed independently of the fire PRA, a hybrid approach to the two approaches described above 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 where specific locations are determined to be risk significant, the HRA analyst could take these areas and only review sections of the fire procedures specific to the risk significant areas.

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 include:

- The specific high level tasks required to achieve the goal of the response.
- Accident sequence specific procedural guidance (fire response procedures).
- The availability of cues and other indications for detection and evaluation errors.
- Accident sequence specific timing of cues, and time window for successful completion.

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 is an iterative process and is included here for completeness for the reader.

3.5 HFEs Corresponding to Undesired Operator Responses to Spurious Actuation

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 primarily consist of shutting down or changing the state of mitigating equipment in a manner that increases the need for safe shutdown structures, systems, or components. The key criterion in identifying undesired operator actions is that it leads to a worsened plant state; for example, turning a transient initiator into a consequential LOCA. If an operator responds to a spurious indication and the action is judged to not impact the CCDP or CLERP, then it does not need to be considered further, except as a dependency on other actions. The dependency evaluation needs to include the potential for prevention of other actions.

In fire events, spurious indications occur when electrical cables routed through a zone where 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. Thus, 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 shut down SI when it is inappropriate to do so.

The undesired operator actions are to be 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 when 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 very pertinent to the scenario. In practice, once the accident diagnosis is complete, required equipment status is verified, and the plant is stabilized (during? to? cooldown and depressurization), the operators would resume normal protocol for monitoring of the control room and start attending to annunciators or alarms again. In a fire scenario, the operators would also implement the fire procedures either in parallel to the EOPs, or the EOPs may be suspended 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 due to 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:

1. Cue parameter(s)
2. Cue (procedural) hierarchy
3. Cue verification
4. Degree of redundancy for a given parameter

Each of the above factors is briefly discussed below:

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 which 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 namely 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(s) on the single parameter would be sufficient, while for a multiple parameter cue, multiple spurious indications on different parameters would be required. It would generally be true that multiple spurious indications on different parameters are less likely to mislead the operators than a spurious indication on a single parameter but the relative likelihood would depend on the fire impact on instrumentation in a specific scenario.

Cue (procedural) hierarchy

Following a reactor trip or safety injection, operator response is governed by procedure. The operators enter the emergency operating procedures (EOPs). During the initial EOP response, the crew basically focuses on plant parameters and alarms that are called out in the EOPs – other annunciator and alarms may be ignored until the plant is stabilized, unless the cue is very 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 this cue. Cues may be further prioritized e.g. Westinghouse EOPs 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:

a) Cues that are continuously monitored.
b) Cues that are called out in the EOPs as checks, but are not continuously monitored.

c) Cues that are not called out in the EOPs, but that may be very pertinent to the scenario.
d) Cues that are not called out in the EOPs and that are not pertinent to the scenario.

Operators are more likely to be misled by a spurious indication(s) on a high priority cue than a low priority cue.

Cue verification

Certain cues may require an immediate response, while other cues may require verification prior to action. For example, a typical annunciator response procedure (ARP) may require the operators to verify the validity of the cue by comparison with the other indications, or by 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 requires 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 may have three or four redundant instrumentation channels. The operators expect all 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 would suspect instrumentation failure. The operators would enter the abnormal operating procedure for instrumentation failure, which would require the suspect instrumentation channel to be placed in the tripped position. However, if additional indications deviate, it becomes progressively more difficult to tell 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.

3.5.1 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 3-1. In the first example, the operators are required to check safety injection (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 RCS pressure is higher than 275 PSIG in E-0 step 25. This step is also a “continuous action step” (denoted by gray highlight) which means that once the operators reach step 25, they will start monitoring the RCS pressure to stop the LHSI pumps if required.

Table 3-1
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	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	PI RCS 402 PI RCS 403	Stop LHSI pumps	Loss of core cooling

For undesired operator actions, continuous action steps are more important because they are monitored and remain in effect until the procedure is exited – in contrast to normal steps that are only performed when the operators reach the step.

Examples of operator actions based on spurious annunciators that could result in undesired responses are listed in Table 3-2.

Table 3-2
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 prob. of success in CCDP calculation. Can be restarted.
CCW PUMP MOTOR INSTANT TRIP	Place the affected pump's control switch in LOCKOUT.	Stopping one CCW pump increases operating temperature on many components, but can be restarted.
EAST RHR PUMP SUCTION VALVES NOT FULL OPEN	Immediately open 1-IMO-310, East RHR Pump Suction, or 1-ICM-305.	Depending on scenario (size of LOCA or not) could lead to cavitation of the pump. Loss of pump in Recirc. mode
RHR PUMPS MOTOR INSTANT TRIP	Place pump control switch in LOCK-OUT.	Delay start of RHR if not on or halts RHR if on. Impacts CCDP. Can be manually started.

3.5.2 Process for Identifying and Defining HFEs that Result in Undesired Operator Response

To ensure the identification task is complete, the following steps 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. The steps below are a summary of the above discussion.

Step 1) Review EOPs for undesired operator response actions
The EOPs are to be systematically reviewed to identify all the steps where an undesired operator action can result. The EOPs to review are those that the operators are expected to perform for all the 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 should the indication associated with the parameter be 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.

Prior to the EOP procedure review, the HRA analyst may benefit from doing preliminary operator interviews in order to more fully understand how the crew anticipates responding to spurious indications and actuations. At most U.S nuclear power plants, crews are trained to rely on multiple and diverse indications before taking actions. 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 have a proceduralized verification step can be screened from consideration, if the verification will be effective given the fire scenario.

Step 2) Review ARPs for undesired operator response actions
The annunciator response procedures (ARPs) are to be systematically reviewed to identify potential undesired operator actions that can result from an annunciator or alarm. The identification process would be analogous to that for the EOPs described above. The ARPs to review would be any ARP which 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 the initial implementation thereof, the annunciators or alarms will remain “in alarm” and will eventually be responded to. Prior to the ARP review, the HRA analyst may need to do preliminary operator interviews to understand how the crew anticipates responding to spurious indication. The same assumptions applied to the EOP review for screening of undesired operator actions can also be applied to the ARP review.

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. The definition should include:

- The specific high level tasks required to achieve the goal of the response.
- Accident sequence specific procedural guidance (fire response procedures).
- The availability of cues and other indications for detection and evaluation errors.
- Accident sequence specific timing of cues, and time window for successful completion.

Additionally, the undesired end state should be included in the definition.

Further discussion on how and what to consider in the definition of the HFE is presented in Section 4.2. The identification and definition is an iterative process and is included here for completeness for the reader.

3.6 Initial Assessment of Feasibility

Once the operator action has been identified and the HFE defined, the HRA analyst needs to initially determine if the HFE is feasible. If it is not feasible the HEP should be set to 1.0. In this stage of the HRA analysis, the goal of the preliminary feasibility assessment is to identify those actions that should not be credited, ultimately reducing the total number of HFEs requiring further analysis. After the preliminary results have been incorporated into the model, additional resources can be used to re-asses 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. To initially determine the feasibility the following information should be addressed qualitatively and early in the HRA task to avoid unnecessary analysis:

- **What are the critical operator tasks required for success?** Based on the procedure review during the identification step, the HRA analyst should know how the operators are going to diagnose the need for the action (for example, the action is proceduralized in the fire procedures or EOPs, or there are several control room alarms) and what types of tasks are involved in its execution (e.g., if the operator has to turn two local valves 600 times or has to start a pump from the control room). The identification of the critical tasks required for success may not include sufficient information to qualitatively determine feasibility, but this identification, in combination with the following additional items, should be sufficient to initially verify feasibility.
- **Is the location where the action is accomplished accessible?** If any of the critical tasks are required in the same location as the fire, or it is known that the operators will not be able to reach the location(s) due to the fire, then the HEP should be set to 1.0.
- **Sufficient time to complete the action.** The analyst should ensure there is sufficient time available to complete the action. If there is not, then the HEP should be set to 1.0. This item involves determining both the total time required to accomplish the action and the time available. 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 estimated based on thermal-hydraulic calculations or by engineering judgment early in the overall NUREG/CR-6850 quantification tasks.

- **Is there enough staff available to complete the action?** If there are not enough crew members available to complete the action (the number of people required for each task exceeds the crew available), then the HEP should be set to 1.0.
- **Has the fire impacted equipment such that required critical tasks can not be performed?** This item includes the instrumentation and/or alarms used as the cue(s) for the operator response, or if the component that is to be manually started/stopped/re-aligned is damaged by the fire. If the fire has damaged the equipment such that it will not function even if the operator takes the appropriate action, then the HEP should be set to 1.0. For example, if the auxiliary feedwater pump is affected by fire then the operator will not be able to restore the pump locally. Any one of the above criteria could provide sufficient information to determine if the action is not 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 items are considered collectively it becomes obvious that this HFE is not feasible.

In the identification and definition stage, the entire narrative and detailed information about each PSF may not yet be known, but consideration of the above should allow the HRA analyst to make a preliminary qualitative assessment about feasibility. The feasibility step is not unique in the identification and definition stage, but this process is iterative - as more information is known about the HFE, the feasibility could be re-assessed (see Sections 4 and 5).

3.7 HRA/PRA Modeling

Once human failure events (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 HRA tasks are performed, especially qualitative analysis (e.g., review of relevant procedures) and quantitative analysis tasks. In deciding which actions to credit initially, the analyst may choose to perform some sensitivity analyses to determine if 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. It is recommended that all actions treated in the internal events PRA and those necessary to achieve safe shutdown in fire procedures be included in the fire PRA.

HRA analysts should use existing guidance on the interface between the HRA and PRA tasks, including how HFEs are modeled and placed into PRA logic models. For example, in Section 5.2.3.1 of NUREG-1792 [3], it is recommended that HFEs "…be placed in proximity …to the component, train, system, and function affected by the human failure event." Also, in Section 3.9.2 of NUREG-1624 [4], it is recommended that the need for altering the PRA logic model in order to accommodate HFEs, especially errors of commission (such as undesired responses to spurious indications) may be needed, especially if the HFEs only occur in very specific contexts.

3.8 References

1. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*. September 2005. NUREG/CR-6850/EPRI 1011989.
2. ASME RA-Sb-2005, "Standard for PRA for Nuclear Power Plant Applications", December 2005, (Note statement in Foreword about standards). Available from American Society of Mechanical Engineers.
3. NUREG 1792, "Good Practices for Implementing Human Reliability Analysis (HRA)", Sandia National Laboratories, 2005.
4. *Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications.* May 2007. NUREG-1824 & EPRI 1011999.
5. NUREG-1852, "Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire", October 2007.

4
QUALITATIVE ANALYSIS

4.1 Introduction

All HRA methods require a qualitative analysis prior to quantification. In the SHARP1 process, [1] this analysis is embedded in the identification and definition step and, in ATHEANA, [2] it is considered explicitly. For fire HRA, the qualitative analysis involves defining the HFE narrative in the context of the fire PRA and developing an understanding of Performance Shaping Factors (PSF). Qualitative analysis is needed as input to the quantification. This report addresses two approaches to non-screening quantification, either a scoping approach, or a detailed analysis. Both quantification approaches need qualitative analysis, but the level of detail required for a given HFE differs depending on whether a scoping or a detailed approach to quantification is used. This section includes an overview of the issues that are to be considered in performing a fire HRA. It is based upon guidance in the ASME PRA standard [3], SHARP1 [1], ATHEANA [2] and NUREG 1792 [4]. It is important that this section be reviewed prior to performing the fire HRA, whether using the scoping or a detailed approach. The information in this section will provide a useful understanding of the issues associated with the fire context and will support the specific qualitative analysis required for quantification. Specific guidance for addressing these fire context issues during quantification are provided in the relevant sections, but the information in this section establishes a knowledge base that is important for thoughtful application of the quantification approaches.

4.2 HFE Narrative

1. Accident sequence (preceding functional failures and successes)
2. Timing information
3. Accident-specific procedural guidance
4. Availability of cues and other indications for detection and evaluation of errors
5. Preceding operator errors or successes in sequence
6. Operator action success criteria
7. Physical environment

For existing internal events HRAs, much of their definitions will remain unchanged for the fire HRA; however, these definitions should be verified to ensure that all PSFs are accounted for appropriately in the context of fire. Additionally, the scoping approach to quantification and the EPRI method both assume that the internal events HRA meets Capability Category II. This assumption should also 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 if the action is risk significant or non-risk significant in order to meet ASME standard requirements HR-F2. [3]

4.2.1 Accident Sequence Preceding Function Failures and Success

For fire PRA, the initiating event is a fire that causes a reactor trip. The reactor trip can either be caused by the fire itself or by fire-induced equipment failures that lead to initiators such as LOOP, or LOCA from stuck open PORV, which will also lead to an automatic or manual trip the reactor.

Following the reactor trip, functional failures and successes are identified to understand how all 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 upon.

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

4.2.2 Timing Information

In the "Identify and Define" step described in Section 3, the timing information was identified such that a qualitative statement could be made about the feasibility of the action. Specifically, the method simply asks, "Is there enough time to complete the action?" For quantification, the following detailed timing information needs to be defined:

- the total time available – 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 (detect, diagnose, decide), and
- The time to execute the response, including 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 analyses such as FSAR, MAAP calculations, or vendor specific studies. The time it takes for operators to formulate and execute a response can be obtained from:

- Plant specific demonstrations per the guidelines presented in Sections 4.3.2 and 5.2.2
- Plant specific simulator data
- Plant specific operator interview
- Job performance measures (JPMs; for actions outside control room)
- Estimation

Usually, combinations of the above approaches will need to be used to obtain as realistic estimates as 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:

- Delays in implementing EOP procedures due to first implementing Fire procedures
- Increases in manipulation time due to additional work load
- Increase in cognitive response due to misleading or unclear indications
- Increases in manipulation time due to additional travel time for local actions.

4.2.3 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, there may be procedural guidance in both the Fire procedures and the EOPs. If the procedural guidance is unavailable, then the HFE can still be developed into an HEP by using the requirements of the ASME PRA Standard high level and supporting requirements of HR-H. This section invokes additional requirements and justification in order to be a credible story for success of this action.

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

The cues should be defined at a functional level as well as the specific components required. The definition includes how the instrumentation is impacted by fire. Secondary cues that could impact recovery are also to be identified. In fire scenarios, it should be confirmed if the cues and indications that are credited for the relevant internal events operator actions are still valid. Note the fire impact may directly affect the cues and instrumentation. The deterministic safe shutdown analysis typically provides for at least one safe shutdown path. For fire scenarios where all redundant trains are failed, then the HEP is initially set to 1.0.

4.2.5 Preceding Operator Errors or Successes in Sequence

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

4.2.6 Operator Action Success Criteria

The specific operator actions required for success needs to be defined. This includes identifying, the sub-tasks, the locations of each sub-task, who (STA, local operator, control room operator) will perform each sub-task and any potential recoveries.

4.2.7 Physical Environment

The fire could have 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.

4.2.8 Fire PRA Context

Each of the above categories 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, [5] each fire area is quantified for complete room burn-up. At this stage of the fire PRA development, screening values such as those provided in NUREG/CR-6850 [5] would be applicable since the purpose of Task 7a is to screen out fire compartments based on quantitative screening criteria. Additionally, the fire response scenarios may not be fully defined such that a complete detailed HRA analysis cannot be performed. For example, the detailed timing information will come from Task 8 which may or may not be completed yet. 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) and thus any HFE requiring this instrumentation should be assumed failed. Additionally if the HFE requires a local action be performed in the fire location the HEP should be set to 1.0.

Starting in task 8 up through the early quantification of Task 11 of NUREG/CR-6850, [5] for potentially risk-significant compartments, a scoping approach is used for quantification. A scoping analysis for HRA quantification is considered more detailed than NUREG/CR-6850 screening but less detailed than a complete HRA. At this stage of the FPRA development, many HFEs have not been screened out and performing a detailed analysis could be very resource intensive since, as the fire PRA is further refined, more HFEs will be screened out.

HFEs required for final quantification in Task 12 of NUREG/CR-6850 [5] must be defined in the greatest level of detail since these HFE 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 verified by simulator or plant walk-downs, the preceding operator successes and failures must be identified and any potential recoveries identified.

4.3 Performance Shaping Factors (PSF)

Performance shaping factors (PSFs) are interdependent and their impact on the human error probability is complicated. However, for practical analysis, the PSFs are often treated independently and are discussed as such below. The purpose of this section is to describe which PSFs need to be addressed for fire HRA. This 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 what to consider for fire HRA. In many cases, the same guidance for internal event events can also be applied to fire and is reproduced here for clarification. The implementation of these PSFs is discussed within the appropriate section for quantification. (Scoping is addressed in section 5.2 and the section C-7 for the EPRI approach) The following is a listing of the PSFs to consider 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, NUREG-1792, NUREG-1852, and the PRA Standards [3-6].

4.3.1 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 hence 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 be credible anymore if either (1) the indications are impacted by the fire, or (2) the associated instrumentation cable routing is unknown. To still be able to credit such actions, it must be shown that there are either (1) alternative (redundant or diverse) indications that are not impacted by the same fire, or (2) that the minimum required instrumentation is sufficiently protected and procedurally identified as such. [7] lists the minimum instrumentation required to be protected, which includes:

- 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 pressure and level (wide range, PWR),
- source range flux monitor (PWR),
- suppression pool level and temperature (BWR), and
- emergency or isolation condenser level (BWR).

For fire HRA, it can be assumed for the instrumentation listed above that there will always be a minimum set of instruments available. However, protection of one train of instrumentation does not necessarily mean that the operators will know which train to use. The system by which the operators identify the protected trains should be verified during operator walkthrough or talk-throughs.

NUREG-1792 [4] 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 where redundancy and/or diversity could be impacted, such as loss of DC or fire, this assumption must be verified.

NUREG-1852 [6] notes that, in addition to the SSCs needed to directly perform the desired function, instrumentation and cues needed to provide diagnostic indications (either EOOs or EOCs) relevant to the desired operator manual actions. These indications, to the extent required by the nature of the operator manual action, may be needed to (1) enable the operators to determine which manual actions are appropriate for the fire scenario, (2) direct the personnel performing the manual actions, and (3) provide feedback to the operators, if not already directly observable, to verify that the manual actions have had their expected results and 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 if a spurious indication appears to be valid within the context of the scenario. Spurious indications that are clearly out of 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 (1) there had not been a trend of increasing temperature, (2) hot and cold leg temperatures are constant, and (3) subcooling margin indications are constant.

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 perform procedure-directed actions under the wrong circumstances or at the wrong time. For example, if the operator follows 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 and their effects that could happen 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 above). Such arguments must be well documented and confirmed by appropriate plant staff (e.g., operators and trainers).

For MCR abandonment actions, it is likely that the crew will have limited familiarity with the ex-CR panels and how cues for actions are presented. Furthermore, the human-machine interface of these panels may not be as good as in the MCR. These issues must be considered in evaluating the adequacy of relevant cues for post-MCR abandonment actions. In addition, in cases of MCR abandonment or use of alternate shutdown approaches, the general effects of crews no longer having access to all the information in the MCR needs to be evaluated.

4.3.2 Timing

Timing is one of the more important PSFs and needs to be considered up front to determine the feasibility of a postulated operator action. An operator action is considered feasible if the time available exceeds the time required. In Section 3, an assessment of its feasibility was used as an initial basis for deciding whether to even model an action. In Section 5, demonstrating the feasibilities of the actions being modeled is a key aspect of the scoping quantification approach. While the more detailed HRA methods discussed in Appendices C and D may not explicitly address feasibility, the timing issues discussed in this section are also relevant to those approaches.

In determining feasibility the time available is typically derived from thermal-hydraulic studies and is the period from the initiating event (fire induced reactor trip) until an undesired or irreversible plant damage state is reached, e.g., core damage. NUREG-1852 [6] suggests that time available should consider unique fire-specific uncertainties such as (1) nature of the fire (fast or slow), (2) fire detector response times, and (3) air flows that can impact fire growth. However, because fire detection and suppression in NUREG/CR-6850 [5] is based on empirical non-suppression data curves, these factors are implicitly accounted for and need not be considered explicitly in the fire HRA.

The time required considers three aspects:

1. the time at which the cue occurs relative to the initiating event
2. the time it takes the operators to formulate a response (detect, diagnose, decide) and
3. the time to execute the response including time required to travel to a local area, if necessary.

The time it takes to formulate and execute a response is not easily measurable. It is not as simple as watching an operator perform an action in ideal conditions with a stop watch to determine the time required to perform the act. Only when the sequence context is considered holistically with the interfacing PSFs can more meaningful “times” be estimated. Thus, to demonstrate the feasibility of HFEs modeled in the fire PRA, the actions should be walked through and timed under as realistic circumstances as possible.[1] For example, if personnel would need to wear SCBAs to perform an action in a fire scenario, then they should wear the gear when an estimate of the time to diagnose and complete the action is obtained. For fire scenarios, even simple MCR actions may need to be simulated to some extent in order to get realistic estimates of required times. However, it is clearly not possible to simulate all potential conditions during a fire that could affect the time to diagnose and perform an action, so some judgments about the time required given the expected conditions will have to be estimated. For use in the HRA scoping quantification approach described in Section 5, a time margin (the difference between the available and required time) is used to account for the uncertainties associated with fire conditions that could impact the time required to complete an action. Time margins and demonstrating feasibility consistent with the guidance from NUREG-1852 [6] are discussed in more detail in Sections 5.2.2 and 5.2.3.

NUREG-1792 [4] 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.

- Crew
- Cues
- Human Machine Interface
- Complexity of action involved
- Special Tools or Clothing
- Diversions and other concurrent requirements
- Procedures
- Environmental conditions

[1] The PRA standard ASME/ANS RA-Sa – 2009 item HR-G5 discusses basing the “required time to complete actions on action time measurements in either walkthroughs or talkthroughs of the procedures or simulator observations” to meet Capability Categories II and III. Just prior to the issuance of this draft, a point was made by the PWR owner’s group regarding the extent of credit that can be taken for talkthroughs due to issues involved in scheduling walkthroughs or simulator exercises with operator crews. Since the scoping approach was developed based on the assumption that walkthroughs would be performed, a further analysis will need to be conducted by the Guidelines team to re-evaluate how the use of talkthroughs would impact the use of the scoping approach HEPs. This will be initiated concurrent with the public review and comment period.

NUREG/CR-6850 [5] provides the following examples of how the overall estimates of the time available and time needed 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., disable 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 alternative 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 completion of the actions within the time available (such as the environmental conditions discussed below and elsewhere in this document) must be considered in determining the HEPs.

Demonstrating Feasibility and the Use of Time Margins

As discussed above, demonstrating feasibility involves showing that a given action or set of actions can be diagnosed and executed within the available time. To support HRA quantification, particularly the scoping quantification approach described in Section 6, it is important that estimated action times are based on a demonstration of the action or set of actions that is as realistic as possible. Time-authenticated demonstrations of the actions, involving actual execution of the actions to the extent possible, are an important requirement of the approach.

In performing a demonstration, the times for both diagnosis and execution, once the relevant cues for the action occur, need to be determined. There are a number of activities that may influence the time to respond, such as:

- MCR staff obtaining the correct fire plan and procedures once the fire location is confirmed
- MCR staff informing the plant staff of the fire and calling for fire brigade assembly and actions
- MCR staff alerting and/or communicating with local staff responsible for completing various actions
- MCR staff providing any specific instructions to the responsible local staff for the actions

- having the local staff collect any procedures, check out communications equipment and obtain any special tools or personnel protective equipment necessary to perform the actions
- performing the actions wearing SCBAs or personnel protective clothing
- traveling to the necessary locations
- implementing the desired actions. It should be noted that some actions may have to be coordinated or done sequentially [i.e., cannot start until prior actions are completed and the MCR staff or others are informed, who also may be dealing with the fire brigade and handling multiple procedures (EOPs and Fire procedures)]
- informing the MCR staff and others as necessary that the actions have been successfully completed and the desired effect has been achieved.

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 included in the demonstration to determine feasibility. However, there are a number of other situations or factors in the fire context that may be very difficult to recreate. Examples include:

- The operators may need to recover from/respond to difficulties such as problems with instruments or other equipment (e.g., locked doors, a stiff handwheel, 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 the demonstration, such as:
  - radiation. For example, the fire could reasonably damage equipment in a way that radiation exposure could be an issue in the location in which the action needs to be taken, causing the need to don personnel protection clothing (which takes extra time), but which may not be included in the demonstration.
  - smoke and toxic gas effects. These are not likely to be simulated in a demonstration, but in a real fire where the manual action needs to be taken in a separate room near the fire location, there may be smoke and gas effects that could slow the implementation time for the action although wearing SCBAs could be simulated.
  - increased noise levels from the fire fighting activities, operation of suppression equipment, or personnel shouting instructions
  - water on the floor possibly delaying the actions
  - obstruction from charged fire hoses
  - heat stress which requires special equipment and precautions or too many people getting in each others' way.
- All these effects may not be simulated in a demonstration, but should be considered as possible, perhaps even likely, when determining the time that it may take to perform the manual action in a real situation.

- The demonstration might be limited in its ability to account for (or envelop) all possible fire locations where the actions are needed and for all 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 operator manual actions (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/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 demonstration because of normal plant status and/or safety considerations while at power (e.g., operators cannot actually operate the valve using the handwheel, but can only "talk-through" doing so).

In addition, there are a number of factors involving typical and expected variability among individuals and crews that could lead to variations in operator performance (i.e., human-centered factors), such as the following examples:

- physical size and strength differences that may be important for performing the actions
- cognitive differences (e.g., memory ability, analytic skills)
- different emotional responses to the fire/smoke
- different responses to wearing SCBAs to accomplish a task (i.e., some people may be more uncomfortable than others with a mask over their faces, thus affecting action times)
- differences in individual sensitivities to "real-time" pressure

It should be noted that, given the likely experience and training of plant personnel performing the actions, it need not be assumed that the above characteristics would lead to major delays in completing the actions. However, their potential effects should be considered in the specific fire-related context of the actions being performed, to confirm this assumption.

The point above is that, although good demonstrations are important for demonstrating feasibility, there are many factors in fire scenarios that could affect the time required to perform the actions that may not be explicitly addressed. Thus, although a reasonable demonstration can provide confidence that the action is feasible under the assumed conditions, it is necessary to show that there is some time margin available in order to have confidence that factors not observed during simulation would not usually prevent the action from being completed. When using the HRA scoping quantification approach in Section 5, in addition to meeting certain criteria with respect to particular PSFs, analysts will be asked whether the action being quantified has been demonstrated to be feasible and whether there is a time margin available to account for unexpected influences on action completion times, such as those described above. Different HEPs will be assigned based on the size of the time margin (e.g., 50% or 100%) and on other factors addressed in the scoping analysis flow charts. Thus, analysts will need as realistic estimates of the time margins as possible, or at least acceptable conservative estimates of the time margins. Guidance for demonstrating the feasibility of the relevant actions is provided in Section 5, based on the guidance in NUREG-1852 [6] for demonstrating the feasibility of operator manual actions.

4.3.3 Procedures and Training

As stated in NUREG-1852 [6] there are three roles of plant procedures, which can aid 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.

As stated in NUREG/CR-6850, [5] depending on the fire, the operators may need to use other procedures or controls 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 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 very helpful in uncovering difficulties in using the relevant procedures. In contrast to EOPs, the fire response 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.

Should any fire response actions be 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 FPRA is further developed, there may be a desire to credit non-proceduralized actions. These cases could be considered, provided that following requirements Supporting Requirement HR-H2 of the ASME Standard [3] 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 procedure, training, skill-of-the-craft exist

(c) attention is given to the relevant performance shaping factors provided in HR-G3

(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. Additionally, it must also be known that:

- There is enough time for the operators to diagnosis and perform the tasks
- There are enough crew members 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.

Like procedures, training for both control room and local actions is an important factor when assessing operator performance. As stated in NUREG- 1852, [6] training supports three functions for operator performance during a fire:

1. Training establishes familiarity with the Fire procedures and equipment needed to perform the desired actions, as well as, potential conditions in an actual event,
2. 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, and
3. Training gives the opportunity to personnel to practice their response without exposure to adverse conditions, thereby 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. But for fire HRA, the crew’s familiarity and level of training (e.g., types of scenarios, frequency of training or classroom discussions and/or simulations) for addressing the range of possible fire complications and potential actions to be performed may be less than for internal events. "Less familiarity" needs to be accounted for in assessing the impact of training for fire actions and in determining their HEPs. 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. Guidance for addressing these issues relative to the scoping approach is provided in Section 5.2.9. This concern is an area of uncertainty since there are typically no 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.

4.3.4 Complexity

As stated in NUREG-1792, [4] 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 vs. 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 complicated steps in a procedure, or poor human-machine interface. 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 in order for the action to be successful (especially if it involves multiple persons in different locations), whether the activity may require very sensitive and careful manipulations by the operator. The more these “measures” describe an overall complex situation, this PSF should be identified as a negative influence. To the extent these “measures” suggest a

simple, straightforward, unambiguous process (or one that the crew or individual is very familiar with and skilled at performing), this factor should be found to be nominal or even ideal (i.e., positive influence).

For local and MCR abandonment actions, the crew may be required to visit various locations and as the number of location increase the complexity of the situation is increased. 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 accounted for.

4.3.5 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 (see Swain and Guttmann [8] for a more detailed definition and discussion of stress and workload). To the extent that crews or individuals expect to be under high workload, time pressure, and stress, it is generally thought to have a negative impact on performance (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 of the other PSFs thought to be relevant. For example, in internal events HRA, if the scenario is familiar, its procedures and training are very good, and if the crews usually implement their procedures within the available time, then 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 only considered adequate, and the time available to complete the action has been shortened due to 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 above, the available time as perceived by the operators. The hazards associated with performing the actions will also be relevant.

For HRA methods that categorize stress into different levels such as low, moderate, and high, a new highest level of stress may want to be considered for fire HRA. This higher stress level recognizes the potential for larger combinations of negative PSFs that could occur during a fire and increase the stress above what is considered high stress for internal events HRA.

4.3.6 Human Machine Interface

Human Machine Interfaces (HMI) impact operator performance differently depending on the location of the action. In general, NUREG-6850, NUREG-1852, and NUREG-1792 [4-6] all agree that, for control room actions, the human machine interface (HMI) will have minimal or positive effect on the human performance. This minimal effect recognizes that problematic HMIs have either been taken care of by control room design reviews and improvements or they are easily worked around by the operating crew due to the daily familiarity of the control room boards and layout. However, any known very poor HMI should be considered as a negative influence for an applicable action even in the control room. For control room actions for fire HRA, the human machine interfaces will remain similar to 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. Thus, 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 to turn the valve with a tool while in an awkward position, or in-field labeling of equipment is in poor condition and could lengthen the time to find the equipment, then 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 alternative 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 and the shutdown panel and related interfaces are plant specific and design reviews and improvements have not always been completed. Additionally, the operators are not as familiar with the panel layout as they are in for control room scenarios.

HMI PSFs need to be considered in combination with other PFSs. NUREG-1852 [6] does not explicitly discuss the HMI, but it does reference NUREG-0711, "Human Factors Engineering Program Review Model," [9] in the context of environmental conditions and communications in so far 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 that "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 "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 in performing demonstrations for feasibility.

4.3.7 Environment

If the fire does not directly impact the control room, the environmental conditions inside the control room are not usually relevant to success of operator actions since they rarely change control room habitability. However, if the fire directly affects the MCR either 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, environmental conditions could be an important influence on the operator performance. Radiation, lighting, temperature, humidity, noise level, smoke, toxic gas, even weather for outside activities (e.g., having to go on a potential 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 considerations 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 considerations may adversely impact the operator actions in the locations where the actions are to be taken and along access routes.

During a fire, there is the potential that the crews ideal travel path to the action location will be blocked by the fire and will lead to a delay or inability to reach the action location. Where alternate routes are possible, the demands associated with identifying such routes and any extra time associated with using the alternate routes should be factored into the analysis. Pursuant 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.

4.3.8 Special Equipment

Due to varying environmental conditions during a fire, the crew may require the use of special equipment. These items, identified in NUREG-1852 [6] as portable equipment can include: keys, ladders, hoses, flash lights, clothing to enter high radiation areas, and fire special protective clothing and breathing gear. 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 success of local fire actions than control room actions.

Abandoning the MCR might also call upon the need to don protective gear or self contained breathing apparatus (SCBA). The hindrance of the special clothing on the operators’ actions needs to be accounted for.

4.3.9 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 how previously considered actions are performed, checks should be made to ensure unique fitness needs are not introduced. Unique fitness needs could include:

- 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, using an especially heavy or awkward tool.
- Physical demands of using respirators. Wearing a respirator could impact communication as well.

4.3.10 Crew Communications, Staffing, and Dynamics

Crew Dynamics

Crew/team dynamics and crew characteristics are essential to understanding 1) how and where the early responses to an event occur, and 2) 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 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 the crews. A review of team dynamics typically includes the following, as described in NUREG-1792 [4].

- Are independent actions encouraged or discouraged among crew members? Allowing independent actions may shorten response time but could cause inappropriate actions going unnoticed until much later in the scenario.
- Are there common biases or “informal rules?” For example, is there a reluctance to do 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 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 there 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 (“we trust the procedures” type of attitude), thereby 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 very 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 re-considered. 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 less opportunity to recover from previous mistakes. Such differences may be best determined by talk-through with operations staff, as well as observing simulated responses of fire scenarios. The main goal of such an analysis is to determine whether there are any particular crew characteristics or team dynamics that could impact a given accident scenario and human action being addressed. Certain characteristics may be fine for most scenarios, but could cause problems in others.

Crew Availability

Fire can introduce additional demands for staffing resources beyond what is typically assumed for handling internal events. These demands can take the form of needing to use and coordinate with more personnel to perform certain local (ex-CR) actions, as well as with the fire brigade and/or local fire department personnel. According to NUREG-1792, [4] for control room actions, the availability of staff is generally not an important consideration for internal event PRA since plants are supposed to maintain an assigned minimum crew with the appropriate qualified staff available in or very near the control room. One of the key assumptions in NUREG/CR-6850 [5] is that 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.

For other ex-control room local actions, crew availability of staff can be an important consideration particularly dependent on (1) the number and locations of the necessary actions, (2) the overall complexity of the actions that must be taken, and (3) the time available to take the actions and the time required to perform the actions.

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

Communication

For both internal events and fire HRA control room actions, communication among crew members should be verified. Typically there will be an established strategy 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 with special air packs and masks on 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 less than ideal environment or situation. It should be understood how equipment faults caused by the fire could affect the ability for operators to communicate as necessary to perform the desired act(s). For instance, having to set up the equipment and talk over significant background noise and possibly having to repeat oneself many times should be a consideration, even if only as a possible "time sink" for the time to perform the act. For fire conditions, the necessary communication devices to carry out the desired actions may or may not be available. For example, the plant loudspeaker coverage may be disabled due to 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 for the crew to need respirators 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, the ability to communicate between different places should be considered and adjusted for. Furthermore, if it is required that SCBA be worn, this apparatus might interfere with clarity in communications between the team. The ability for operators to communicate with each other 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.

4.4 Review of Relevant Experiences

In order for the fire HRA analyst to gain a better understanding of the plant response following an event, he should consider reviewing relevant experiences. The analyst should look at both plant-specific events as well as industry-wide incidents to populate theses 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 an HRA analysis, it is particularly relevant to a detailed HRA analysis 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 to the NRC Information Notices, or similar types of information, as these notices will sometimes include summaries of example events along with a discussion of the problems and surrounding context illustrated by these events.

Conducting a historical review of experiences exposes the analyst to a variety of plant conditions and plant progressions (including timing issues) that should be considered in the HRA analysis. Furthermore, the review may reveal potential influences on operator performances (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 that lead the operators to make errors in responding to the situation. The study of these situations aids the analyst in identifying 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 dependency analysis. These occurrences may have been affected by plant policies and/or the informal rules that operators follow and would thus impact the human error probability. (A historical review of plant-specific and industry-wide events, incidents, and accidents will aid the analyst in detailing the relevant contextual cues surrounding human performance. For instance, the significant PSFs driving the performance in particular events can be identified. To this end, and as a further benefit to reviewing previous events, the discussion among the PRA team members and operations staff is often more productive if the specifics of a historical event can be used as an illustrative example.

4.5 Review of Plant Operations

Prior to detailed quantification, the HRA analyst should confirm with plant operational personnel the general organizational factors affecting fire HFEs such as crew staffing, procedural and communications protocols. Discussion with operators can often reveal that there are “informal rules” among operators about which even the training staff maybe 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 sometimes the use of the procedures is at the discretion of the shift supervisor. At some plants, the fire procedures are implemented in parallel to the EOPs and, at other plants, they are implemented after completion of the EOPs, and, 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 EOP procedures when the diagnosis is clear to the operators or anticipating alarms and acting before the minimum time necessary.

Additionally, it should be confirmed how the crew will interact with the fire brigade. The crew’s tasks during a fire may be varied and these additional tasks would lead to an increased workload. This activity confirms that a minimum set of operators and staff is available to complete the actions.

After each HFE has been quantified, additional operator interviews should be performed. In these operator interviews, plant-specific data is collected through plant walk-downs and operator talk-throughs. The purpose of these interviews is to “tune” the fire PRA model to the accident scenario in question. 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.

4.6 References

1. *Systematic Human Action Reliability Procedure (SHARP) Enhancement Project. SHARP 1 Methodology Report.* December 1992. EPRI TR-101711.
2. NUREG-1880, “ATHEANA User’s Guide”, June 2007.
3. ASME RA-Sb-2005, “Standard for PRA for Nuclear Power Plant Applications”, December 2005, (Note statement in Foreword about standards). Available from American Society of Mechanical Engineers.
4. NUREG 1792, “Good Practices for Implementing Human Reliability Analysis (HRA)”, Sandia National Laboratories, 2005.

5. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*. September 2005. NUREG/CR-6850/EPRI 1011989.
6. NUREG-1852, "Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire", October 2007.
7. Section IX of Attachment I to IN 84-09, "Lessons Learned from NRC Inspection of Fire Protection Safe Shutdown Systems (10 CFR 50, Appendix R)", dated March 7, 1984.
8. 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.
9. NUREG-0711, Rev. 2, "Human Factors Engineering Program Review Model", February 2004.

5 QUANTIFICATION

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

The first methodology 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). In addition, since the screening approach assigns a screening value of 1.0 for main control room (MCR) abandonment or alternative shutdown actions, a possible next step, conservative, approach (similar to an approach presented in NUREG/CR-6850 [1]) is provided at the end of the screening section. This approach allows 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.

In those instances where a less conservative analysis is required, the next stage presented is a scoping analysis. 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, as well as 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 more detailed analysis of the fire PRA scenarios and the associated fire context, and 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 that which could be developed using one of the two detailed HRA approaches also described in this report.

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

1. EPRI detailed HRA methodology [2] approach presented in Appendix C of this report, or
2. ATHEANA HRA method (NUREG-1880) [3] presented in Appendix D

Section 5.3 below 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 those fire scenarios and associated equipment failures and operator actions most significant in the overall fire risk. This process helps rank the fire sequences. The ranking can be used to determine which sequences might be further analyzed to demonstrate low risk by analysis of cable separation or by detailed human reliability evaluations.

The screening methodology presented below 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., first hour) of a fire event and are not expected to be performed until at least one hour after the fire initiation and trip of the plant. Thus, 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 [1] application of the screening criteria produced overly conservative HEPs for the longer term actions. Thus, the screening criteria for Sets 1 and 2 described below have 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 [1].

As discussed in NUREG/CR-6850 [1], the screening methodology described below 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" (see below) is applicable. If the needed screening analysis seems too demanding, analysts always have the option to initially assign screening failure probabilities of 1.0 to all HFEs.

The method supports 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 on going activities in the accident sequence), and ensuring 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 below) cannot be identified or met, no screening value should be used (i.e., assign a 1.0 failure probability initially and/or do a more detailed analysis 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 below (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. Hence, 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 per the ASME Standard [4]. 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 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 below.

5.1.1.1 Screening Values Under Set 1

Given that the criteria for Set 1 exist, 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 Task 7 and beyond.

However, if the actions can be determined to be long term actions in the sense that they would not need to occur until the fire was almost assuredly extinguished, spurious events would no longer be occurring, and they meet all of the other criteria for Set 1, then 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 as follows:

Set 1 Criteria

1. The fire can cause an automatic plant trip, or a forced and proceduralized manual trip, and could not cause significant damage to functional safe shutdown equipment or related instrumentation beyond that considered in the Internal Events PRA for which the HFE value(s) apply. This condition demonstrates that from the safe shutdown perspective, the challenge of the particular fire is not significantly worse (functionally or as to effects on equipment) than already considered in the Internal Events PRA for the applicable HFE(s).

2. Based on input from the cable/circuit analysis, 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. (1) The spurious events are not associated with safety-related equipment and instrumentation relevant to the critical safety functions, and hence will be only minor distractions, not immediate challenges to safe shutdown. (2) The operators can discern the events to be clearly attributable to the fire. (3) 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 attempting to achieve safe shutdown.
3. One train/division of safe shutdown, related equipment and instrumentation is 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 emergency operating procedures.
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 FEPs, those FEPs 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 if someone else is responsible for dealing with the fire-specific response procedures and the actions associated with those procedures do not significantly disrupt the above 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, 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 than in the Internal Events PRA-related scenario(s) for which the HFE(s) apply.
7. A dependency assessment of the applicable HFEs in the Internal Events PRA has been performed per the ASME Standard [4] to ensure that the dependencies are accounted for in the fire PRA. Potential dependencies created either by the fire effects or the associated introduction of new HFEs into the model need to also 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 and that any likely strong dependencies have been accounted for during the screening, so that accident sequences/cut sets are not artificially removed because of multiplying many supposedly independent HEPs together.

8. If any of the HFEs being modeled are local (i.e., ex-control room) manual actions that were 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; and others). It should also be demonstrated that the staff assumed to conduct the action will still be available, i.e., they will not be conducting other fire-related responses such as isolating electrical equipment or supporting the fire brigade, for example. Furthermore, other conditions assumed in evaluating the corresponding Internal Events PRA local action (i.e., need for special tools, communication capability, 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 Task 7 and beyond. In addition, if the HFEs can be determined to be long term actions as described above, then 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 where 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 that were 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[1]. However, if the HFEs are long term actions as described above and they meet all of the other criteria for Set 2, then 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 Standard [4].

Set 2 Criteria

If all of the Set 1 conditions are met except that significant spurious electrical effects are likely to be occurring in one safety-related train/division (and one train/division only) of equipment and/or instrumentation important to the critical safety functions, and hence 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

[1] The Set 2 screening adjustments are intended to conservatively bound the general fire effects on level one actions modeled in the internal events PRA. Examples of such effects are described in Appendix B. Set 2 adjustments do not address operator actions added to the PRA model to address additional fire scenario concerns.

immediate response from the crew. In Set 2, the crew might have to attend and respond to the spurious activity in the affected train/division to make sure it does not affect their ability to reach safe shutdown (e.g., causing a diversion of all injection). However, the crew would likely detect the spurious activity quickly and not be confused by it. 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.

For the long term HFEs, the above conditions would essentially have occurred in the past and things will have 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 needing 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.

Set 3 Criteria

1. If the action being considered is either a MCR or local (i.e., ex-control room) manual action and it 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 thus not continuing to cause delayed spurious activity and other late-scenario complicating disturbances, and that there is plenty of time available to diagnose and execute the action, set the HEP to 0.1 for screening or 10 times the internal events HEP. The analyst still needs to ensure that potential dependencies across HFEs in the models and the joint probabilities of multiple HFEs are accounted for per the ASME Standard [4]. That is, 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 anyway, 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 detailed analysis will likely be needed for these types of scenarios, and thus screening is not appropriate for these cases. An initial possible alternative (similar to an approach initially presented in NUREG/CR-6850 [1]) that allows 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 5.1.1.6 below. This approach allows an initial conservative value to be assigned if certain criteria are met and this value may be adequate for some plants.

Set 4 Criterion

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 values of 1.0. More detailed analysis is needed either before the screening runs of the fire model or afterward (see section 5.1.16 below for a possible initial step).

5.1.2 Examples and Basis for Quantitative Screening Values

It is acknowledged that the above set of screening values do 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); 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 is necessary to avoid being overly optimistic for potentially important and/or complex scenarios and associated HFEs. Table 5-1 summarizes the approach to screening using example values for the HEP from the internal events analysis and the assigned fire screening values.

Table 5-1
Example HEP adjustments and values using fire zone screening criteria

	1	2	3	4
Criteria	**Original HEP Examples**	**HEP considering Fire Effects X10**	**HEP Considering Fire Effects = 0.1**	**HEP Value to Apply**
Set 1 (Existing Level 1 HFEs) example HEP adjustments	0.001	0.01	NA	0.01
Short term example	0.3	[1][1]	NA	1
Long Term example	0.0001	0.001	[0.1][2]	[0.001 or 0.0001][3]
Set 2 (Spurious modification to existing HFEs) example HEP adjustments	0.001	0.01	0.1	0.1
Short term example	0.3	1	[0.1][4]	1
Long term example	0.0001	0.001	0.1	0.001
Set 3 (New or significantly modified HFEs) example HEP adjustments	NA	1	0.1	Use both HEPs in sensitivity analysis
Short term example	0.3	1	0.1	1
Long term example	0.0001	0.001	0.1	0.001
Set 4 (MCR abandonment HFEs) example HEP adjustments	NA	1	[1][5]	[1][6]

Notes

1 The value of an HEP never exceeds a probability of 1.0.

2 For long term events the lower value is recommended - most fires are out by this time and event conditions become static.

3 The original value can be applied for long term events if the fire is out and event conditions are static after the 1st hour.

4 The HEP screening value should never be lower than the original HEP because fires add complexity to the event.

5 Overall success of transfer to remote location is 0.1 in several IPEEs. (See section 5.1.3).

6 Recovery HEPs are 1.0. Detailed analysis needed for HEPs below 1.0.

5.1.3 Single Overall Failure Probability Approach for MCR Abandonment or Alternative 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 alternate 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. This approach is not recommended by this guideline unless a detailed analysis and timeline is done that shows that more than adequate time is available to conduct all of the actions required to abandon the MCR, set up the alternate shutdown means, and accomplish each of the actions required to reach safe shutdown. In addition, the time required for the plant conditions to reach a state where the crew would decide to abandon the MCR must also be considered. In other words, the time it would take for the MCR to become uninhabitable (see Section 11.5.2 of NUREG/CR-6850 [1]) or the time it would take to reach a state where the plant could no longer be completely controlled from the MCR due to fire effects NUREG/CR-6776 [5], would have to be factored in to the analysis (including likely crew hesitancy to abandon the MCR). Substantial extra time (i.e., a time margin of at least 100% for the set of actions required) should be available before a screening value *such as* 0.1 should be used and the basis for meeting the criteria discussed above should be carefully documented.

It should be noted that from a CDF perspective, this approach will probably not be as preferable as using the scoping or detailed HRA strategies. Explicitly modeling HFEs for critical human actions associated with achieving safe shutdown using alternative means should usually lead to a lower CDF. As long as the actions are feasible (there is adequate time to perform all of the actions), there is a time margin available to account for unexpected fire effects, there are procedures available, the crews are trained on the procedures, and other PSFs do not overly limit their likelihood of success, then the combined HEPs for the relevant HFEs using these strategies should generally be significantly less than 0.1.

5.2 Scoping Fire HRA Quantification

The scoping fire HRA quantification approach allows assignment of HEPs to new HFEs identified specifically for the fire PRA (i.e., outside the Internal Events PRA) and to HFEs which are carried over from the internal events analysis that survive quantitative screening (i.e., they are important enough that a less conservative, more realistic HEP is needed).[2]

There are minimum criteria that 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 criteria.

In addition to meeting the minimum criteria, the scoping fire HRA quantification approach requires that the actions associated with the HFE be demonstrated as being feasible within the time allotted. Section 5.2.2 describes how to perform a feasibility demonstration and its elements. In addition, Section 5.2.3 covers how to determine the time margin available and Section 5.2.4 discusses PSFs relevant in the scoping fire HRA approach.

Once the minimum criteria have been met and the feasibility has been demonstrated, then 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 search scheme (Section 5.2.6 and Figure 5-2) is provided first to direct the analyst to the correct scoping quantification guidance for the HFE being considered. The flowcharts provide a means of obtaining HEPs (assumed to be mean values) for four categories of actions that are associated with the following HFEs:

[2] The scoping fire HRA approach is used to quantify the probability of failure of the action or actions (which may include multiple subtasks) that are represented within a single HFE.

1. New and existing MCR actions (Section 5.2.7 and Figure 5-3),
2. New and existing ex-control room actions (Section 5.2.8 and Figure 5-4),
3. Actions associated with abandoning the MCR or using alternate shutdown means due to MCR habitability issues or due to difficulties in controlling the plant exclusively from the MCR because of the effects of the fire (Section 5.2.9 and Figure 5-5), and
4. Cases where the fire may affect critical instrumentation, thereby creating the potential for errors of commission (EOCs) or errors of omission (EOOs) due to incorrect indications (Section 5.2.10 and Figure 5-6). The flowcharts for spurious indications will support addressing spurious instrument effects as described in ANS Fire PRA standard (HLR-ES-C1 and C2 [6]).

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

5.2.1 Determine Minimum Criteria

In order to use the scoping approach to quantify the modeled HFEs, the feasibility of the action must be demonstrated (discussed in Section 5.2.2) and the following minimum criteria relative to several PSFs need to be met. It should be noted that meeting these criteria establishes only the minimum criteria and does not preclude additional consideration of these PSFs later on in performing the scoping analysis.

1. Procedures – There should be plant procedures (e.g., fire-specific procedures, emergency operating procedures, alarm response procedures, abnormal operating procedures and/or normal operating procedures) covering each operator action being modeled. The procedures should support both 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 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).
2. For HFEs modeled to recover EOOs or EOCs caused by spurious instrumentation, although procedures will usually support recovery of such actions, in some cases operators may be able to rely on the scenario context and additional cues (in conjunction with the existing procedures) to recover those errors. In these cases, specific procedural guidance directing the recovery per se may not always be available, but arguments can be made that the existing procedures, in conjunction with operator training and available cues will be adequate to support 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).
3. Training – Operators should have received training on the procedures being used and on the actions being performed. The training should establish familiarity with the procedures, the equipment needed to perform the desired actions, and how to successfully execute the action. The training should be performed per the plant’s normal training practices and, if appropriate, include special considerations given the desired actions will need to be carried

out during a fire (e.g., wearing SCBAs while performing the action). When subtasks must be coordinated among more than one person to complete the action, the training should also cover how to conduct the coordination and communication aspects of the action.

4. Availability and Accessibility of Equipment – It should be shown that all equipment and tools needed to perform the modeled human actions during a fire will 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 below).

5.2.2 Demonstrate the Feasibility of the Operator Actions

With the minimum criteria met, a key analysis to support the scoping fire HRA approach is the demonstration of the feasibility of the actions modeled in the HFE. All of the scoping flowcharts used to quantify HFEs included in the models assume that the actions have been demonstrated to be feasible. As discussed in Section 4, demonstrating feasibility involves showing that a given action or set of actions for a particular HFE can be diagnosed and performed within the time available. That is, an operator action is considered feasible if the time available exceeds the time required. The time available is typically derived from thermal-hydraulic studies and is defined as the time from the initiating event (fire induced reactor trip) until an undesired or irreversible plant damage state is reached, e.g., core damage. The time required for operator performance should consider three aspects:

1. The time at which the cue occurs relative to the initiating event,
2. The time it takes the operators to formulate a response (detect, diagnose, decide), and
3. The time to execute the response including time required to travel to a local area, if necessary.

To support the scoping quantification approach, it is important that the action times are estimated based on an actual demonstration of the action or set of actions that is as realistic as possible. That is, the actions (including diagnosis) should be walked through and timed while simulating the fire scenario and including the requirements of the action to the extent possible.[3] However, it is acknowledged that 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 they might affect the crews' ability to respond to an accident scenario. Thus, 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 judgments of plant personnel, then a process should be used to help ensure that the estimates are reasonable (e.g., get multiple independent judgments). As long as a

[3] The PRA standard ASME/ANS RA-Sa – 2009 item HR-G5 discusses basing the "required time to complete actions on action time measurements in either walkthroughs or talkthroughs of the procedures or simulator observations" to meet Capability Categories II and III. Just prior to the issuance of this draft, a point was made by the PWR owner's group regarding the extent of credit that can be taken for talkthroughs due to issues involved in scheduling walkthroughs or simulator exercises with operator crews. Since the scoping approach was developed based on the assumption that walkthroughs would be performed, a further analysis will need to be conducted by the Guidelines team to re-evaluate how the use of talkthroughs would impact the use of the scoping approach HEPs. This will be initiated concurrent with the public review and comment period.

reasonable effort is made in conducting a realistic demonstration and knowledgeable plant staff are used to provide estimates where needed, time margins (discussed below) will be used to provide a way to account for potential shortcomings in the ability to adequately simulate the actual plant conditions during the demonstration.

Ideally, in order to get as realistic estimate of the time required to perform the actions as possible, several crews would be used in conducting the demonstrations. However, since this may not always be possible, at least one randomly selected, established crew should participate in the demonstration. Since data from one crew may not be representative of all crew response times, 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. Conservative HEPs are also assigned to help bound the uncertainties.

In addition, while it is easiest to conceptually imagine each action being individually demonstrated for different fire scenarios, it is acknowledged that some actions and the fire scenario contexts may have characteristics that are very similar (e.g., the actions themselves are similar, timing related to when the actions have to be performed and how long it would take to implement the actions are similar, locations for the actions are not vastly different as to significantly affect travel time to the locations, similar environments exist for the locations for the actions). In such cases, with justification, a demonstration of an action for a given scenario could be argued to bound or otherwise represent other similar actions in similar circumstances. Hence, one demonstration may be sufficient to credit other similar actions under similar situations. Furthermore, if a demonstration of feasibility was completed at an earlier date (e.g., to meet criteria in NUREG-1852 [7]), and the conditions have not significantly changed, the feasibility of the actions do not need to be demonstrated again.

How to Perform a Demonstration

This section provides information on what should be considered and how to ensure that the demonstration is appropriate (it is based on related guidance in NUREG-1852 [7]). The first step in performing a demonstration is to ensure that the minimum criteria discussed above in section 5.2.1 have been met. After that, the main goal is to include in the demonstration all aspects that could influence the outcome of the actions, if it is reasonable to do so. Things to consider for inclusion are discussed below.

Before proceeding, it should be noted that, to the extent reasonable, the entire fire-induced accident scenario should be simulated for the demonstration, including all the expected cues and MCR activities. More details on the nature of the simulation are given below. While it is desirable that any demonstration simulates the fire conditions to the extent reasonable, under all circumstances, the demonstration is to be done considering the ability to replicate expected fire conditions safely for personnel, and without jeopardizing the safe operation of the plant. All actions associated with detecting and diagnosing the presence of the fire and diagnosing the need for and executing the relevant actions should be timed during the demonstration. Obviously, this information will be important in determining whether there will be enough time available to perform the actions.

Environment – The environmental conditions expected to be present in the areas which operators will have to access to complete the actions, as well as in the locations of the actions, should be simulated to the extent reasonable (noting the safety considerations cited above). For example, the following conditions could be simulated in all relevant areas, including areas through which the operators may have to travel:

- The lighting levels expected to be present during the actual fire to the extent feasible and safe.
- If the environmental conditions are assumed to involve the use of SCBAs at any time in the scenario, then the donning and wearing of these during those periods.
- If protective clothing will be needed at any time, then the donning and wearing of these during those periods.
- If SCBAs may be needed, then any communications anticipated during those periods when the SCBAs are worn (personnel who use SCBAs must receive training and be qualified in their use).

Equipment Functionality and Accessibility – Accessibility to the relevant systems and equipment is necessary to enable the personnel to perform the operator actions. To the extent possible, the personnel participating in the demonstration should carry out the actions (including accessing the equipment) if the actions can be done without affecting the safety of the plant (e.g., manually open a valve with the handwheel). As noted earlier, if the demands of the task and the time to complete the actions must be based on the judgments of plant personnel, then a process should be used to help ensure that the estimates are reasonable (e.g., get multiple independent judgments). A preferred approach is to obtain estimates of the time to execute specific actions when safety is not a concern (e.g., during shutdown or when the system is out of service for some reason).

In addition, if the plant history indicates that certain equipment tends to have persistent types of problems (e.g., a tendency for valve hand wheels to be stiff), then those conditions should be assumed for the demonstration and not "pre-conditioned" solely for the demonstration.

Available Indications and Main Control Room Response – In conducting the demonstration, the actual effects of the fire conditions should be simulated, to the extent possible, in the plant training simulator and the operators should diagnose the need for the relevant actions based on the expected pattern of indications (including cues expected to be affected by the fire). In addition, the presence of the cues needed to detect the fire should be simulated and the crew should have to respond accordingly. The MCR response to the scenario should be the same as during an actual fire. The MCR crew should enter the relevant procedures based on the expected indications and take the necessary steps to respond to the fire and reach hot shutdown. The parameters indicating the need for the operator actions in response to the fire (fire procedure responses) should also be simulated, and the crew should have to summon the staff necessary for the actions, retrieve the relevant procedures, provide the necessary guidance, and interact with the individuals as necessary while they complete the actions for the demonstration. In addition, the personnel executing the actions should have to check relevant indications of successful completion of the actions and verify completion. These indications should be accurately simulated to the extent possible.

All aspects of the scenario associated with diagnosis and the execution of the actions should be timed. This will provide information relevant to determining the time to diagnose the need for the actions and the time needed to implement the actions. If any aspects of the scenario cannot be simulated, their potential impact on the time should be estimated.

Communications – The communications necessary to complete the operator actions should be part of the demonstration. This should include communications necessary from the detection of the fire through completion of the actions. Examples of conditions that should be included in the demonstration include the following:

- If it cannot always be assumed that the personnel expected to perform the actions will be in the control room at the time they will be needed, then consideration for where the personnel might be with respect to being able to communicate with the control room should be included in the demonstration. If personnel might be in areas where someone would have to be sent to get them, then this activity should be simulated.
- If personnel must be able to communicate with each other and with the control room, then those communications and the devices that will have to be used should be part of the demonstration.

Portable Equipment – Any portable equipment that will be needed to conduct the actions during a real fire should also be accessed and used to the extent reasonable during the demonstration. Portable equipment includes unique or special tools, such as keys to open locked areas or manipulate locked controls, flashlights, ladders to reach high places, torque devices to turn valve handwheels, and electrical breaker rackout tools. Such equipment should be located where it would be expected to be located during a real fire. The equipment should not be gathered together and made easily accessible just for purposes of the demonstration (i.e., no “pre-conditioning”).

Personnel Protection Equipment – Similar to the portable equipment noted above, any personnel protection equipment such as protective clothing, gloves, and SCBAs should be located, accessed, and donned as during an actual fire.

Procedures and Training – Activities associated with the use of procedures should be addressed in the demonstration, including the following:

- detection of the entry conditions for the procedures
- retrieval of the procedures
- the potential need for multiple copies
- usability of the procedures under the expected condition (e.g., lighting levels, a place to put them during their execution if they must be closely followed).

In addition, while the selection of a crew for the demonstration should be random, it should be ensured that there has been no pre-conditioning such as limiting the selection to only those crews most recently trained.

Staffing – Staff who will have duties associated with successful completion of the actions (including diagnosis and execution of the actions) should participate. Staffing issues such as the following should be considered in the demonstration:

- If personnel will have to be summoned from outside the MCR, how long it will take them to get to the control room should be assessed as part of the demonstration considering the likely starting locations for the personnel based on where these persons are typically located. Plant staff should consider the potential for the personnel to be in remote locations from which it is difficult to egress and that the personnel may have to complete some actions before they can leave an area if this is the typical situation for some staff members. It would then be preferred that these considerations be included in the demonstration.
- If the actions will involve multiple staff in certain sequences, then these activities, their coordination, and their associated communication aspects should be included.
- If the MCR crew is likely to be directing and coordinating multiple teams involved in executing manual actions, these activities should be simulated. Furthermore, if the individuals in the MCR coordinating these activities will have other significant responsibilities, those responsibilities should also be simulated.

Other Aspects Important to the Demonstration – There are several other important issues or aspects that plant staff should consider in conducting an appropriate demonstration:

- If the fire or other factors could affect where personnel have to travel (e.g., what routes they have to take) and where they have to enter and exit various rooms, then this should be considered in the modeling for the demonstration and determining the travel time.
- If the conditions that could be generated by the fire have the potential to vary significantly, this should be accounted for when deciding how to model the scenario(s) for purposes of the demonstration.
- If smoke could significantly affect visibility, the action should generally not be credited.

In general, plant staff should strive to make the demonstrations as realistic as possible and make conservative assumptions as necessary. If this is done and the above information is followed, then the resulting timing information obtained from demonstrations should provide a good basis for determining the feasibility of the actions. Once an action has been demonstrated to be feasible (i.e. it has been shown that the time required to perform the action is less than the time available), additional factors are evaluated in order to estimate the HEP for the action using the scoping flowcharts. These include estimating the available time margin for the action and addressing other key factors that could influence the likelihood of success under fire conditions.

5.2.3 Calculation of Time Margin

As discussed in section 4.3.2 and immediately above in section, 5.2.2, it is clear that in spite of plant staff's best efforts, there may be conditions that are very difficult, if not impossible, to simulate. This is one of the reasons it is necessary to show that additional time is available beyond that required based on the demonstration (i.e., to provide a way to account for potential shortcomings in the ability to adequately simulate the actual plant conditions during the demonstration). That is, a tradeoff exists between the extent to which the demonstration is realistic, and the uncertainties to be addressed as part of justifying there is adequate time to perform the action. For instance, more realistic demonstrations translate into less uncertainty with regard to justifying there is adequate time. Similarly, the more crews that can participate in the simulations, the less uncertainty associated with 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 (the difference between the total available time and the time required, essentially the extra time available) to obtain certain HEPs. In addition, different time margins may be required if the presence of certain conditions (e.g., short vs. long time frame events or simple vs. complex actions) suggest the potential for greater sensitivities to the effects of the fire or greater variability in crew response times. Thus, 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.

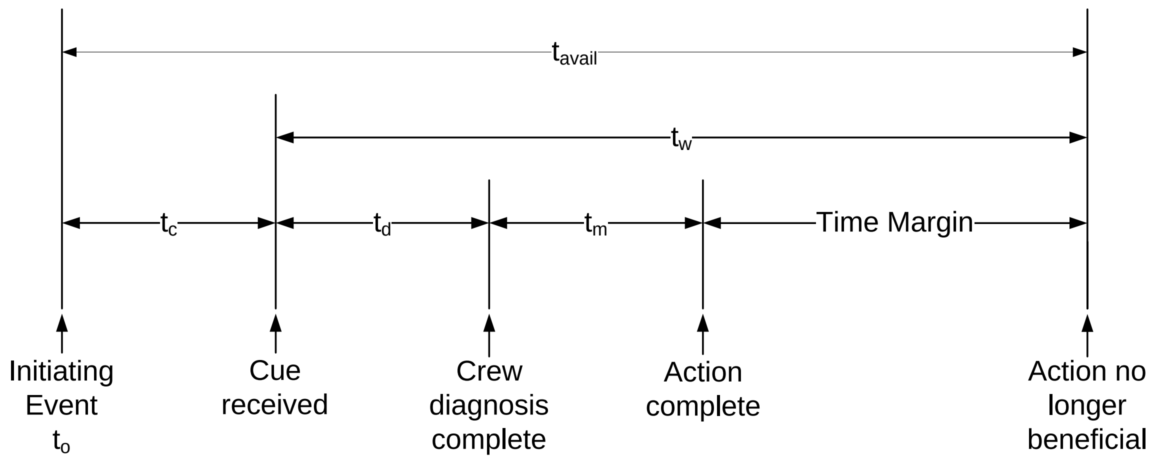

Figure 5-1
Timeline Illustrating total time available, time required, and the resulting time margin

In this diagram, t_{avail} is the total time available from the initiating event until the action is no longer beneficial. The time window, or t_w, is the amount of time available to perform the action including diagnosis and execution. The other variables are as follows: t_o is the time of the initiating event, t_c is the time from the initiating event until the cue(s) is received, t_d is the time to diagnose the problem and formulate the response, and t_m is the manipulation time, or time required to execute the action.

Time margin can be calculated as:

$$TM = \frac{t_w - (t_d + t_m)}{(t_d + t_m)} * 100\%$$

Time margins should be calculated for all actions or sets of actions (underlying a given HFE) being modeled and quantified using the scoping approach, and in some cases at least, 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 they may involve a mix of both serial and parallel actions, and some tasks may overlap. In these cases, determination of the time margin may not always be as straightforward as illustrated above, since the time for the tasks taken together, including where they overlap, needs to be considered in determining the time margin available, 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, then the execution time may only require 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.

5.2.4 Assess Key Conditions and PSFs

In applying the scoping flowcharts, in addition to addressing the timing issues discussed above, there are decisions that must be made regarding particular conditions and PSFs that could affect performance of the actions. Some of the decisions are required in all of the flowcharts and others are specific to particular flowcharts. General guidance for making these decisions is provided in this section, but in some cases there are details associated with particular conditions and PSFs that 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 (i.e., due to habitability issues). Similarly, questions are asked in all of the flowcharts regarding smoke levels for areas in which operators will be performing actions in or through which areas 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 dense enough smoke to cause visibility problems and prevent the action from being taken. These determinations will be part of the fire modeling tasks (Task 8, Scoping Fire Modeling, and Task 11, Detailed Fire Modeling) and the information will have to be supplied to the HRA analysts based (probably) on 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.

Assessments important to scoping flowcharts

Do the procedures match the scenario? – An important question asked in several of the flowcharts-, concerns the diagnosis of a given action. In particular, it is asked if 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, then 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 well, it should be assumed that the diagnosis will be difficult and the HEP for the action should either 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 the cases where the fire could lead to effects on specific instrumentation and EOOs or EOCs are possible [SPI flowchart, 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 only quantified at two levels, either high or low. In deciding on the level of execution complexity, a number of aspects are evaluated (note that the guidelines below 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 (trained personnel should be able to follow them straightforwardly) or the action can be considered skill-of-the-craft,, then generally low complexity can be assumed.
- Multiple step actions – If the HFE requires multiple steps to be completed for success, then 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 (and trained personnel should be able to follow them straightforwardly) or the actions can be considered skill-of-the-craft, then low complexity can generally be assumed. Yet, if there are any 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), then 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 between team members to successfully complete the action, then 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 between the staff members is required. Generally, if multiple locations must be visited to complete the action, then high complexity should be assumed.

- Multiple functions – Multiple functions may need to be performed 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 performed, the complexity should be assumed to be high.
- 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 in performing the action. To the extent 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. Thus, while the guidance above 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, then they should be considered in assessing complexity level, generally leading to low complexity actions being assessed as high.

It should be noted that several of the factors that could add to complexity are already included in the scoping flowcharts. In addition, the demonstration of feasibility will show that the action is not so complex that it cannot be performed in the time available and the time margin is intended to account for other factors that may not have been explicitly included in the demonstration 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. Thus, two of the flowcharts (in MCR actions and Ex-control room actions, Figures 5-3 and 5-4) explicitly ask whether the cue or cues for an action will occur while the fire is ongoing. Based on the information in NUREG/CR-6850 [1], for application of the scoping flowcharts, it is assumed that most fires (exceptions noted below) will be extinguished or contained within 60[4] minutes of the start of the fire. Thus, upon entering the two flowcharts noted above, the time from the beginning of the fire to the presentation of the cue for an action needs to be determined. For the purposes of the scoping analysis, the start of the fire is considered to be concurrent with the initiating event. Although this is rarely the case in actuality, estimating the times to be such allows a conservative estimate as to the effect of the fire on the diagnosis and execution of the action.

Depending on when the cues occur, analysts will take different paths through the flowcharts. If the cue is expected to be received more than 60 minutes after the fire has started or the plant has tripped, it can usually be assumed that the fire has been suppressed or contained. An important exception to this rule are more challenging fires such as fires of turbine generators, outdoor transformers, high energy arching faults, and flammable gas fires. For modeling of actions during these events, the analyst should always assume the cue occurs before the fire has been suppressed, regardless of when the cues occur relative to the start of the fire. Similarly, for cues

[4] Some have argued that fire suppression time (e.g., non-suppression time in NUREG/CR-6850[7]) should be assumed to be 70-75 minutes rather than 60 minutes in order to include time to detect the fire. Pending NRC and industry resolution of FAQ-50 (which addresses this issue) fire suppression time is assumed to be 60 minutes from the start of the fire.

received within the first 60 minutes of the start of the fire, the fire is considered to not yet be under control. HFEs quantified in these situations will be assigned a slightly higher HEP to account for direct and indirect effects of an ongoing fire.

Action time window – The time window 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. For actions that have a short time window, additional consideration is given to the time margin and determining feasibility. For the scoping flowcharts, it is assumed that short time window actions (<= 30 minutes, approximately) will be more susceptible to diversions and distractions caused by the occurrence of the fire in the plant. Thus, short time window actions are given different treatment in the scoping flow charts than longer time frame actions (> than 30 minutes, approximately). This different treatment is applied whether the cue for the action occurs during on-going fire suppression efforts or afterward. If the action time window is equal to or less than 30 minutes, the analyst is directed one way in the flowchart and another direction if the action time window is greater than 30 minutes, resulting in the need for somewhat greater time margins for short time frame actions. As noted above, the reasoning is that actions with shorter time windows will be more sensitive to even minor diversions and distractions associated with the occurrence of the fire and will, therefore, need somewhat larger time margins to absorb these effects and still complete the action.

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 (hereafter referred to as smoke levels) present in the areas of the actions or in areas personnel must travel through 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 dense enough smoke to cause visibility problems and prevent the action from being accomplished. As discussed briefly above, these determinations will be part of the fire modeling tasks (Task 8, Scoping Fire Modeling, and Task 11, Detailed Fire Modeling) and the information will have to be supplied to the HRA analysts based (probably) on 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 in to account. Note that smoke removal systems that can be assumed to be functioning can be taken in to 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 low enough level as to not require the use of any breathing apparatus (e.g., SCBA).
- Smoke or hazardous elements are at high enough level such that breathing gear (e.g., SCBA) is required.
- Smoke levels are high enough to affect visibility and prevent 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 due to habitability issues are addressed separately in the section on the search scheme for selecting the appropriate flowcharts for the action (Section 5.2.6.1) and in the section on MCR abandonment flowchart (Section 5.2.9).

Accessibility – In the scoping flowcharts for ex-control room actions (Figure 5-4) and MCR abandonment or alternative shutdown actions (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 due to the presence of the fire and on-going attempts to suppress the fire. 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. If either of these is true, the action cannot be credited.

5.2.5 Basis for Scoping Fire HRA Quantification 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 that which could be derived if a more detailed and time-consuming HRA analysis was performed.

Like 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 and the NRC Individual Plant Examination of External Events Program), 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 the demonstrations of feasibility, reasonable time margins, and other PSFs. A discussion on the basis of the HEPs quantified through the use of the scoping fire HRA method as well as the further justification behind the requirements of demonstrating feasibility and a certain time margin are given in Appendix H.

Within a flowchart, the HEPs are based on the following characteristics:

- Timing of the cue for an action relative to the start of the fire
- Length of action time window
- Level of diagnosis complexity
- Level of execution complexity
- Level of smoke at area of action or in areas to be passed through
- Accessibility of action site

5.2.6 Guidance for Using the Search Scheme (Figure 5-2)

In the identification and definition section (Section 3), HFEs were identified and categorized as: 1) internal events operator actions (existing operator actions from internal events PRA model), 2) fire response operator actions (operator actions explicitly called out in the fire procedures) and 3) undesired operator actions (due to spurious instrumentation). This particular classification helps to understand how the HFE was identified, but for the purposes of scoping fire HRA quantification, the HFE needs to first be further classified.

In the scoping fire HRA quantification approach, HFEs are treated based on conditions within the MCR, the location of the actions associated with the HFE (MCR or ex-control room), and the condition of relevant instrumentation. The search scheme (Figure 5-2) uses pertinent questions in determining which action is being quantified and directing the analyst to one of the following flowcharts: in MCR action, ex-CR or local action, MCR abandonment or alternative shutdown, or recovery of error due to spurious instrumentation.

In some instances, the HFE may be quantified within the Search Scheme. For instance, the first question in the Search Scheme flowchart (Figure 5-2, Decision 1 [D1]) asks if the feasibility of the action being quantified has been demonstrated. Specifically, this demonstration addresses whether there is time to diagnose and perform the action under the expected conditions (e.g., as an in control room action or as an action taken after MCR abandonment). If the action has not been demonstrated as being feasible per the guidance in Section 5.2.2, an HEP of 1.0 can be assigned immediately.

Two other cases exist in the search 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 an in-MCR or ex-control room action (D6), the question is asked (D5) whether the procedures match the scenario (i.e., do the cues received by the control room staff to support diagnosis match the procedural guidance? See Section 5.2.4 for guidance on this decision). If the cues do not match the procedures (D5), 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 either procedures are present for directing the steps of the action, or the execution is skill-of-the-craft (D7). Again, if these procedures or skills do not exist, the action is assumed to fail (HEP = 1.0).

Notice that the HEPs assigned in the Search Scheme flowchart are identified with labels (e.g., SS1). These labels are provided for all HEPs assigned through the use of the flowcharts. The labels are provided primarily to help later in tracing how a particular HEP was decided upon 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 is assignment of the HEP:

- SS = Search Scheme
- INCR = In MCR
- EXCR = Ex-MCR
- CRAB = MCR Abandonment (this label also is used for HEPs quantified during alternative shutdown actions)
- SPI = Spurious Instrumentation

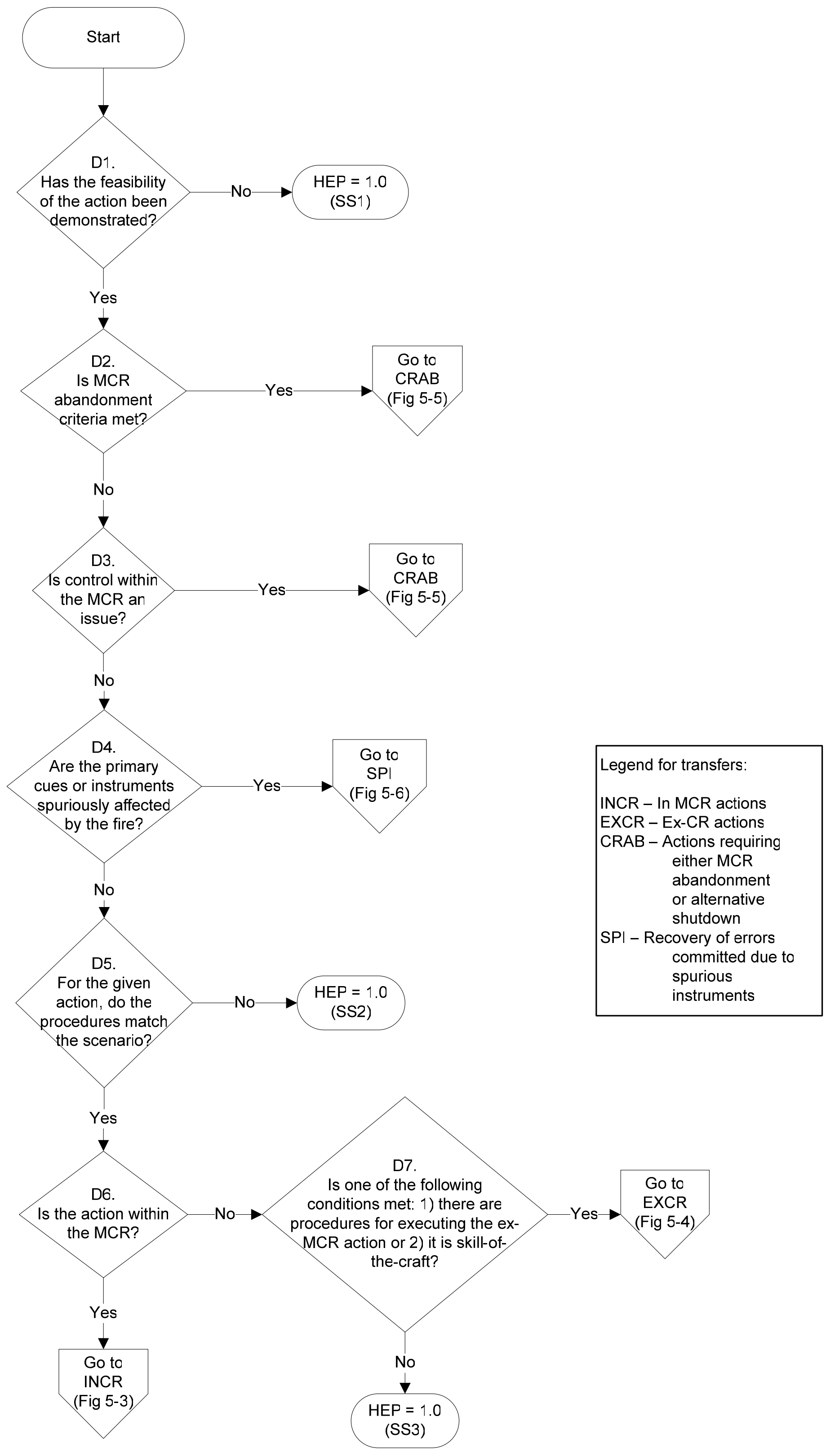

Figure 5-2
Scoping HRA analysis search scheme

Although there are some HFEs that may be quantified with the use of the Search Scheme alone, most HFEs will be directed to the other flowcharts for quantification. A series of questions is asked in the Search Scheme to determine which of the flowcharts is appropriate for quantification. After determining that the action being modeled is feasible (D1), the next decision (D2) determines whether the analyst will be directed to the flowchart quantifying MCR abandonment or alternative shutdown (Figure 5-5; CRAB) based on the control room being uninhabitable or operators having difficulty controlling the plant (i.e., unable to trip the reactor, provide decay heat removal (DHR), or operate systems necessary to mitigate the initiating event) from within the MCR.

Discussion and guidance on interpretation of the questions asked in the Search Scheme (Figure 5-2) and the transitions to other flowcharts are presented in subsections immediately below. Following these discussions, separate sections provide guidance on using the other flowcharts, and the resulting scoping fire HFE quantification:

- Section 5.2.7 – HFEs comprised of actions that take place in the main control room (INCR)
- Section 5.2.8 – HFEs comprised of actions that are diagnosed in the MCR but take place outside the main control room (EXCR)
- Section 5.2.9 – HFEs associated with actions related to abandoning the main control room or using alternate means for shutdown (CRAB)
- Section 5.2.10 – HFEs resulting from responses to spurious indications (SPI)

5.2.6.1 MCR Abandonment/Alternative Shutdown (D2 and D3)

There are two critical factors that influence operators in deciding whether to abandon the main control room:

1. Is the main control room habitable? (Figure 5-2, Decision 2 [D2])
2. Can the plant be controlled from the main control room? (Figure 5-2, Decision 3 [D3])

For fires that either directly cause an uninhabitable environment in the MCR or otherwise make plant monitoring and control extremely difficult from the MCR (unable to control key safe shutdown equipment), the crew may need to leave the MCR and achieve safe shutdown wholly or in part from ex-CR locations. Section 11.5.2 of NUREG/CR-6850 [1] provides criteria for determining when the MCR would need to be abandoned due to habitability issues (D2). To establish timing of this event, it is suggested that at least one of the following criteria from NUREG/CR-6850 [1] be satisfied:

- The heat flux at 6' above the floor exceeds 1 kW/m^2 (relative short exposure). This can be considered as the minimum heat flux for pain to skin. Approximating radiation from the smoke layer as q,' = σ –Tsl 4, a smoke layer of around 95°C (200°F) could generate such heat flux.
- The smoke layer descends below 6' from the floor, and optical density of the smoke is less than 3.0 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 2.13 m (7') apart.

If any of the criteria are met, then subsequent actions will need to be quantified as MCR abandonment actions and analysts will follow the Search Scheme flowchart to the MCR Abandonment/Alternative shutdown (CRAB) flowchart for each action (Figure 5-5). This would include an action to switch control to a remote shutdown panel (RSP) if appropriate.

For cases where the MCR is habitable (D2) but plant monitoring or control becomes difficult due to critical instrumentation and controls for critical equipment being affected by the fire, the crew has a decision to make (i.e., "D3" in Figure 5-2). The two possibilities are:

- To abandon the MCR, or
- They may decide to stay in the MCR (i.e., direct the crew response from the MCR to the extent possible), but collect information or take actions outside the MCR as necessary to reach safe shutdown (referred to as alternate shutdown, which may be standard practice for some plants).

However, when habitability is not an issue, it is reasonable to expect that the MCR would not be completely abandoned.[5] So, the HRA analysis 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 control to a RSP or whether it would be possible to control the plant using an alternate shutdown approach based on the fire response procedures. This determination should be based on interviews with plant operators and trainers and an examination of the plant fire procedures. It is assumed that the crew would try to take whatever actions are necessary to reach safe shutdown, whether they involve using a RSP, taking actions outside the MCR as necessary based on the fire procedures, or even some combination of both, depending on plant practice and available equipment.

If the effects of the fire could be significant enough that switching to a RSP (if available) would probably be required (e.g., large fire in the cable spreading room), analysts will need to estimate when switchover is likely to occur relative to the start of the initiating event. At that point, the analyst can quantify the HFE including the switchover action and all subsequent actions using the CRAB flowchart. The timing for the actions will have to take into account the time to perform the switchover and the timing of the critical cues at the RSP. If it is determined that the operating crew could reach safe shutdown using ex-control actions, as necessary, without switching over to the RSP (use an alternative shutdown approach), then the HFE for these actions would also be quantified using the CRAB flowchart, but the time to accomplish the switchover would not be included, nor would the impact of the switchover on what the operators would do.

A scenario involving MCR abandonment or the need to use alternative shutdown introduces a level of complexity that can not be adequately addressed by quantifying these actions as usual local (i.e., ex-CR) actions. It is likely that many factors may introduce more serious challenges to operator success under these conditions, e.g.:

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[5] 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.

- Less available instrumentation and controls,
- The need for 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 activities that in other situations could easily be done in the MCR.

In general, if it is known that habitability and control of the plant from the MCR would not be affected to the extent that MCR abandonment or alternative shutdown means would be required, then analysts will progress in the search scheme to the next question asking about indicators for the specific actions being affected by the fire (D4).

5.2.6.2 Actions Caused by Spurious Instruments (D4)

Per the fire PRA standard [6], 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 ANS Fire Standard HLR-ES-C1 and C2 for more detail [6]).

Therefore, if the primary cues or instruments used for the action currently being quantified are modeled as being affected by the fire, the analyst is directed (D4) to the flowchart quantifying the recovery of EOCs or EOOs committed due to spurious instrumentation (Figure 5-6; SPI).

If the cues or instruments are fed by “protected” cables, they can generally be assumed to not be affected by the fire. Some instruments and cues associated with safety systems, and in particular, those associated with achieving and maintaining safe shutdown conditions are considered “protected” in accordance with 10 CFR Part 50 Appendix R, or as unaffected in a NFPA-805 project.

For the purpose of scoping quantification, an instrument is considered “protected” if:

1. It’s cables are not routed through the fire area in question, or
2. If the cables are wrapped with a fire barrier which is sufficient for the postulated HFE and the given fire scenario.

However, even if the equipment and cables are protected per Appendix R 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 to direct flame impingement, explosive fires). If the reliability and validity of the cues cannot be ascertained, spurious indications are possible within the MCR, and the analyst should treat the cues as potential spurious indications and use the SPI flowchart (Figure 5-6) for recovery of errors caused by these spurious indicators.

5.2.6.3 In MCR and Ex-Control Room Actions

If the action being quantified deals neither with MCR abandonment or alternative 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 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 actions and ex-control room 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]).

A preliminary question (Figure 5-2, Decision 5 [D5]) in the quantification of these in MCR and ex-control room actions asks if the procedures match the scenario (see section 5.2.4 for guidance). The intention 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 action will fail (HEP = 1.0). If the execution of the action occurs within the MCR, the analyst is directed (D6) to Figure 5-3, 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), one final question regarding the guidance given directing the action is asked (D7). The question addresses:

1. Are procedures available to support executing the action outside the MCR?
2. Can the action (and related subtasks) be assumed to be skill-of-the-craft, thus not requiring step by step procedures?

Skill-of-the-craft actions are those that one can assume trained staff would to 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 options is true, the action is assumed to fail (HEP = 1.0). If one of the options can be assumed, the analyst is directed to Figure 5-4 to quantify the ex-CR action.

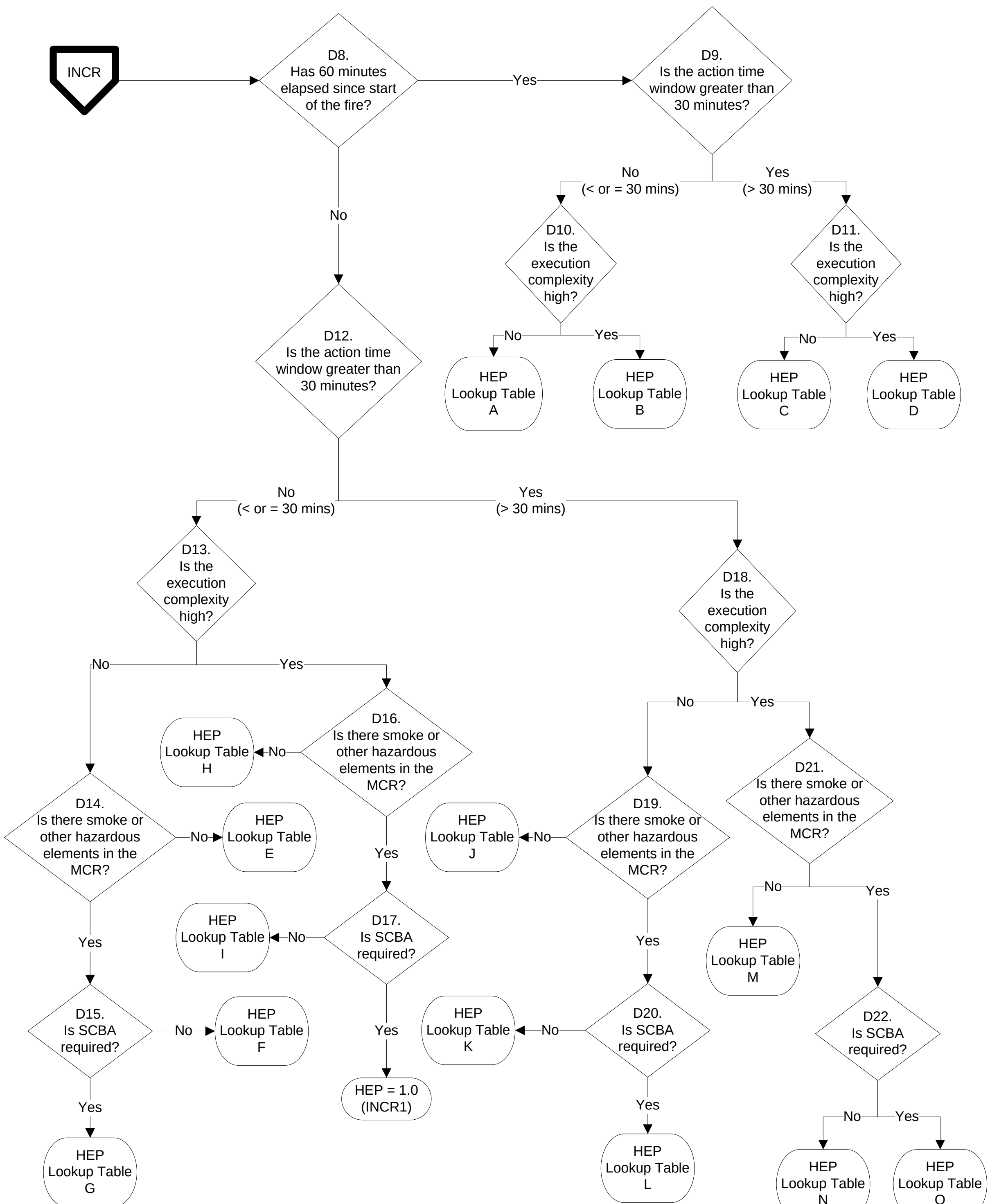

Figure 5-3
INCR - scoping HRA analysis for in MCR actions

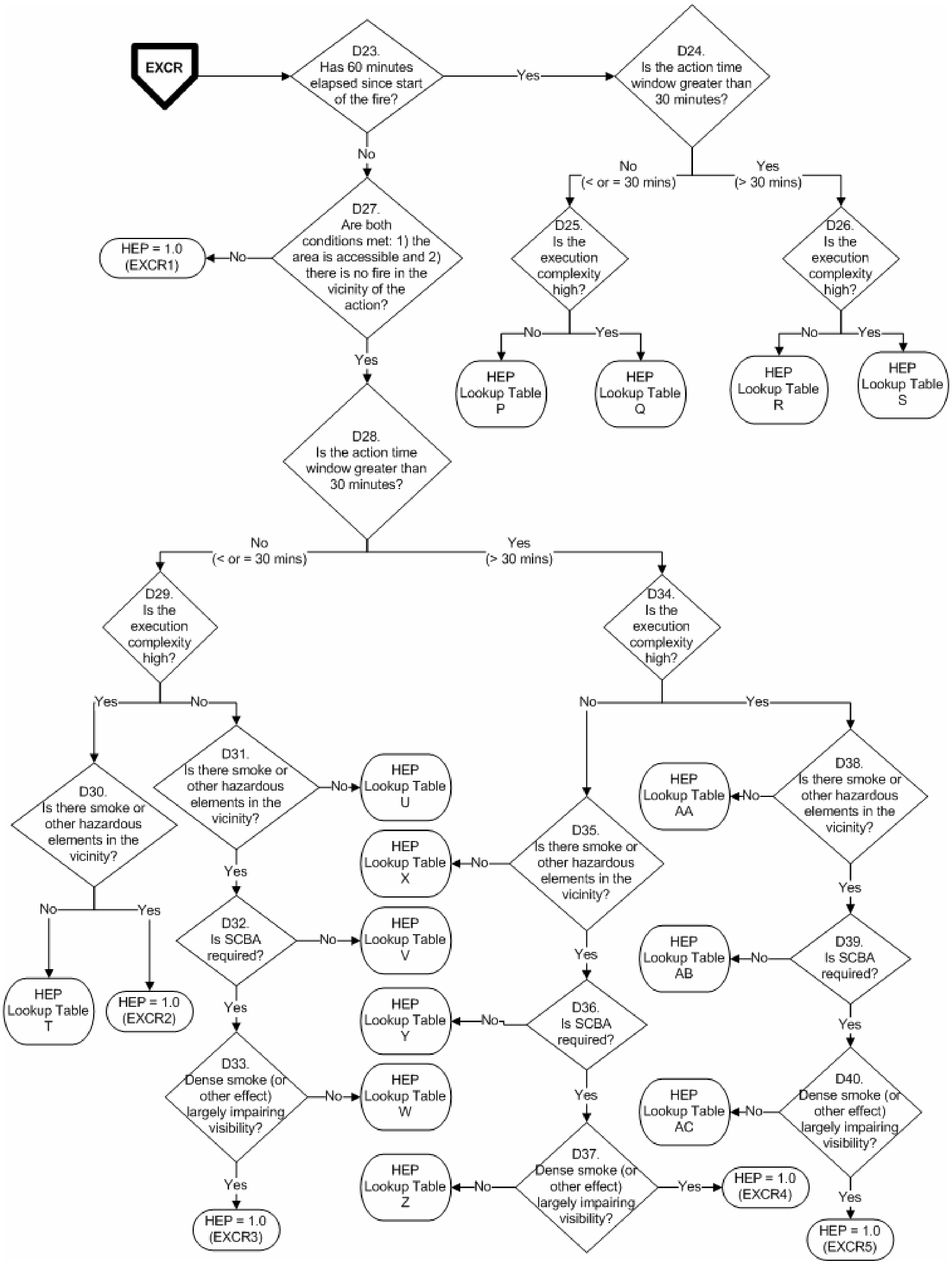

Figure 5-4
EXCR - scoping HRA analysis for EX-CR actions

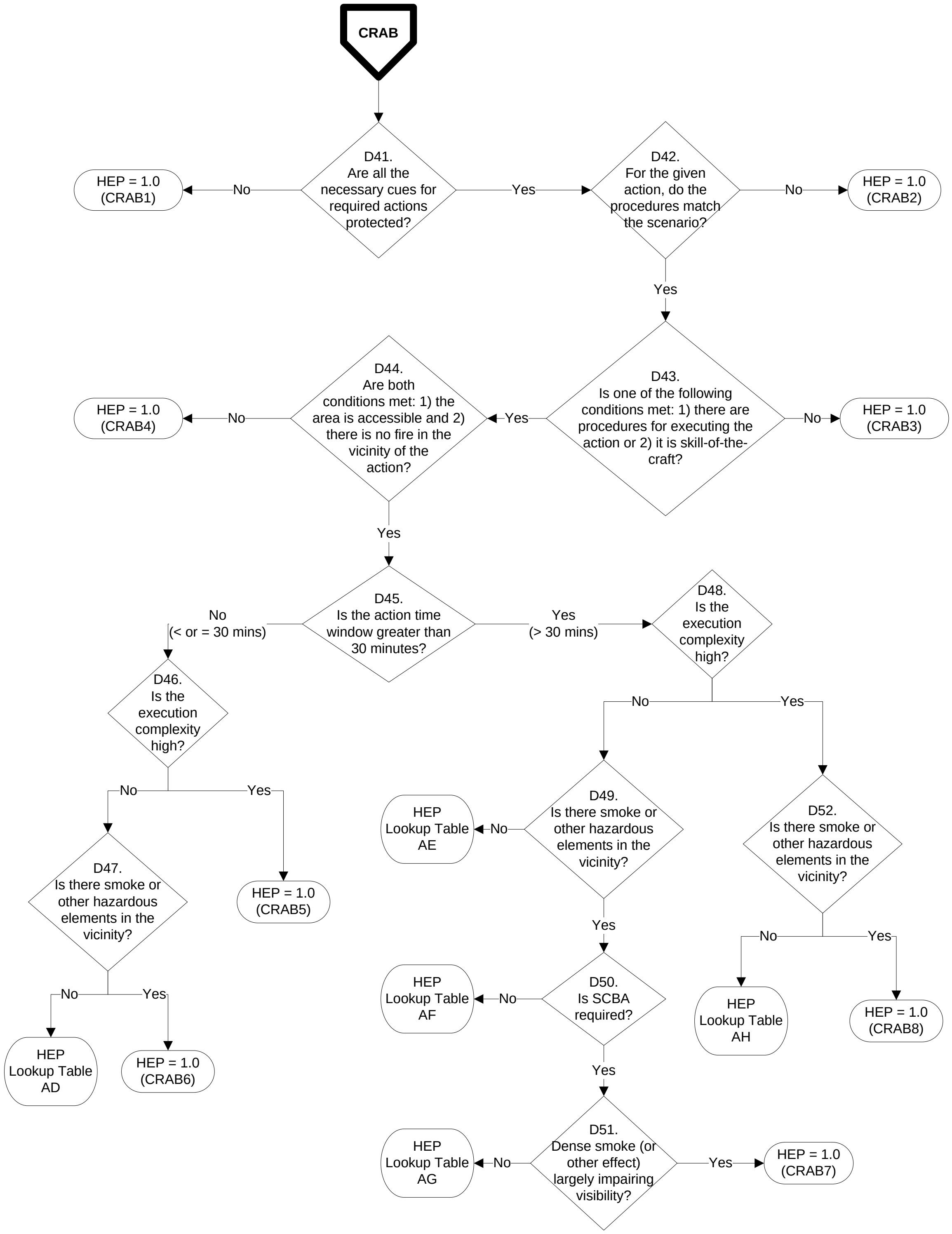

Figure 5-5
CRAB - scoping HRA analysis for MCR abandonment or alternative shutdown actions

5.2.7 Guidance for Using the INCR Flowchart for in MCR Actions (Figure 5-3)

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 that survive quantitative screening.

The flowchart covers both diagnosis and execution of the action in 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 when the cue for an action would occur relative to the start of the fire (e.g., within 60 minutes of the start of the fire or after). If the cue for an action occurs within 60 minutes of the start of the fire as opposed to after 60 minutes, different paths are taken through the flowchart (D8). Note that for more challenging fires such as fires of turbine generators, outdoor transformers, high energy arching faults, and flammable gas fires, the analyst should always assume 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 available time window from when 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 (D9 and D12).
- The level of execution complexity expected; high or low indicates different paths (D10, D11, D13, and D18).
- The expected level of smoke and other hazardous element effects in the MCR (D14, D16, D19, and D21). 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 (D15, D17, D20, and D22).
- An estimate of the time margin for use in the look up 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 of the questions within 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 5-2. Within the lookup table, the HEP assigned for each action is based on the time margin available.

Table 5-2
In MCR actions HEP lookup tables

HEP Lookup Table	Time Margin	HEP	HEP Label
A	≥ 200%	0.005	INCR2
	100 – 199%	0.025	INCR3
	50 – 99%	0.125	INCR4
	< 50%	1.0	INCR5
B	≥ 200%	0.025	INCR6
	100 – 199%	0.125	INCR7
	50 – 99%	0.625	INCR8
	< 50%	1.0	INCR9
C	≥ 100%	0.001	INCR10
	50 – 99%	0.005	INCR11
	< 50%	1.0	INCR12
D	≥ 200%	0.005	INCR13
	100 – 199%	0.025	INCR14
	50 – 99%	0.125	INCR15
	< 50%	1.0	INCR16
E	≥ 200%	0.05	INCR17
	100 – 199%	0.25	INCR18
	< 100%	1.0	INCR19
F	≥ 200%	0.1	INCR20
	100 – 199%	0.5	INCR21
	< 100%	1.0	INCR22
G	≥ 200%	0.2	INCR23
	< 200%	1.0	INCR24
H	≥ 200%	0.25	INCR25
	< 200%	1.0	INCR26
I	≥ 200%	0.5	INCR27
	< 200%	1.0	INCR28
J	≥ 100%	0.01	INCR29
	50 – 99%	0.05	INCR30
	< 50%	1.0	INCR31
K	≥ 100%	0.02	INCR32
	50 – 99%	0.1	INCR33
	< 50%	1.0	INCR34
L	≥ 100%	0.04	INCR35
	50 – 99%	0.2	INCR36
	< 50%	1.0	INCR37
M	≥ 200%	0.05	INCR38
	100 – 199%	0.25	INCR39
	< 100%	1.0	INCR40
N	≥ 200%	0.1	INCR41
	100 – 199%	0.5	INCR42
	< 100%	1.0	INCR43
O	≥ 200%	0.2	INCR44
	< 200%	1.0	INCR45

The termination point of the branch of the flowchart will direct the analyst to the correct row in the HEP lookup table column within Table 5-2. 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.

5.2.8 Guidance for Using the EXCR Flowchart for ex-CR Actions (Figure 5-4)

The flowchart presented in Figure 5-4 (EXCR) walks through the steps of assigning scoping HEPs to HFEs that are diagnosed within the MCR, but that must be executed locally (i.e., outside the MCR). 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 that survive quantitative screening.

Similarly, the flowchart covers both diagnosis and execution of the action, with the main difference being that the actions are executed outside the MCR.

Although the HEPs may be different due to the actions having to be performed outside the MCR, there are only a few differences between the questions asked in the MCR action flowchart (Figure 5-3) and those asked for actions that must be executed outside the MCR (Figure 5-4). The additional pieces of information that will be needed include (following the guidance in 5.2.7):

- A determination of whether the area for the ex-control room action is accessible (D27). If no, credit for the action cannot be taken.
- A determination of whether the action must take place in the direct vicinity of the fire (D27). If yes, credit for the action cannot be taken.
- An estimate of the effects of expected level of smoke and other hazardous elements in the areas where the action must take place (D30, D31, D35, and D38).

Other than answering these questions, analysts will step through the flowcharts for ex-control actions (Figure 5-4; EXCR) just as was done for MCR actions in Flowchart Figure 5.3 (INCR). Lookup tables for the ex-CR flowchart are located in Table 5-3 (see guidance in section 5.2.7 for use of the look up tables).

Table 5-3
Ex-CR actions HEP lookup tables

HEP Lookup Table	Time Margin	HEP	HEP Label
P	≥ 200%	0.01	EXCR6
	100 – 199%	0.05	EXCR7
	50 – 99%	0.25	EXCR8
	< 50%	1.0	EXCR9
Q	≥ 200%	0.05	EXCR10
	100 – 199%	0.25	EXCR11
	50 – 99%	0.5	EXCR12
	< 50%	1.0	EXCR13
R	≥ 100%	0.002	EXCR14
	50 – 99%	0.01	EXCR15
	< 50%	1.0	EXCR16
S	≥ 200%	0.01	EXCR17
	100 – 199%	0.05	EXCR18
	50 – 99%	0.25	EXCR19
	< 50%	1.0	EXCR20
T	≥ 200%	0.5	EXCR21
	< 200%	1.0	EXCR22
U	≥ 200%	0.1	EXCR23
	100 – 199%	0.5	EXCR24
	< 100%	1.0	EXCR25
V	≥ 200%	0.2	EXCR26
	< 200%	1.0	EXCR287
W	≥ 200%	0.4	EXCR28
	< 200%	1.0	EXCR29
X	≥ 100%	0.02	EXCR30
	50 – 99%	0.1	EXCR31
	< 50%	1.0	EXCR32
Y	≥ 100%	0.04	EXCR33
	50 – 99%	0.2	EXCR34
	< 50%	1.0	EXCR35
Z	≥ 100%	0.08	EXCR36
	50 – 99%	0.4	EXCR37
	< 50%	1.0	EXCR38
AA	≥ 200%	0.1	EXCR39
	100 – 199%	0.5	EXCR40
	< 100%	1.0	EXCR41
AB	≥ 200%	0.2	EXCR42
	< 200%	1.0	EXCR43
AC	≥ 200%	0.4	EXCR44
	< 200%	1.0	EXCR45

5.2.9 Guidance for Using the CRAB Flowchart for Main Control Room Abandonment and/or Shutdown Using Alternate Means Actions (Figure 5-5)

The flowchart presented in Figure 5-5 (CRAB) provides analysts with a means of obtaining HEPs for the actions associated with MCR abandonment and/or use of alternate shutdown means. Certain information will be needed to conduct the scoping quantitative analysis, including (following the guidance in section following the guidance in section 5.2.6.1).

- The identification of the necessary cues for the diagnosis of the needed actions and whether the instruments supporting the necessary cues have been verified to be protected from the fire effects (D41).
- The availability of procedures to support the diagnosis of the action, including a determination of whether the procedures related to diagnosing the action will generally match the expected pattern of cues for a given scenario (D42).
- The availability of procedures to support the execution of the action or documentation that the action can be considered is skill-of-the-craft (D43).
- A determination of whether the area for the ex-control room action is accessible (D44). If no, credit for the action cannot be taken.
- A determination of whether the action must take place in the direct vicinity of the fire (D44)? If yes, credit for the action cannot be taken.
- A determination of the available time window from when 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 (D45).
- The level of execution complexity expected; high or low indicates different paths (D46 and D48).
- An estimate of the effects of expected level of smoke and other hazardous elements in the areas where the action must take place (D47 and D49 - D52), for example, will SCBAs need to be worn?

With this information, analysts will be able to step through the decision flowchart for abandoning the MCR or using alternate shutdown and, in most cases, obtain HEPs useable for MCR abandonment HFEs in the fire PRA.

Upon entering this flowchart, the first questions ask if the necessary cues for the action have been verified protected from the effects of the fire (D41) and whether the scenario matches the procedures (D42). If the answer to either is "no", the action is assumed to fail (HEP = 1.0). If the answer to both is "yes", then it is asked whether there are either:

1. Procedures available to support executing the action outside the MCR, or
2. The action (and related subtasks) can be assumed to be skill-of-the-craft, thus not requiring step by step procedures (D43).

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 (D44). If neither the area nor the path to the area are accessible, the action is assumed to fail (HEP = 1.0). If the area and path are accessible, quantification continues similar to those steps taken in ex-CR and in 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 MCR abandonment or use of alternative shutdown flowchart are located in Table 5-4. In determining the time margin to use in the quantification of the actions, the analyst must take into account timing issues important to MCR abandonment or alternative shutdown conditions (e.g., time required to perform a switchover to a RSP or additional time to perform formerly in-MCR actions outside the MCR).

Table 5-4
MCR abandonment or alternative shutdown actions HEP lookup tables

HEP Lookup Table	Time Margin	HEP	HEP Label
AD	≥ 200%	0.5	CRAB9
	< 200%	1.0	CRAB10
AE	≥ 100%	0.1	CRAB11
	50 – 99%	0.5	CRAB12
	< 50%	1.0	CRAB13
AF	≥ 100%	0.2	CRAB14
	< 100%	1.0	CRAB15
AG	≥ 100%	0.4	CRAB16
	< 100%	1.0	CRAB17
AH	≥ 200%	0.5	CRAB18
	< 200%	1.0	CRAB19

Of particular importance is consideration of the time required for the conditions to reach a state where the crew would need to abandon the MCR. In other words, 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 where the plant could no longer be controlled (or completely controlled) from the MCR due to fire effects (see NUREG/CR-6776 [5] for information relevant to determining such timing). These times will have to be factored in to the analysis. These times may also affect assumptions about which operator actions would be performed in the control room prior to abandonment or taking alternative actions 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 abandon the MCR or begin to take shutdown related actions outside the MCR.

Even if the crews do not fully abandon the control room, but use alternative shutdown means (e.g., atypically perform some actions locally), additional timing issues must be considered. An estimate of the time required before the fire could significantly affect plant control from the MCR (see NUREG/CR-6776 [5]) can be used as the estimate of when the crew would need to switch plant control to alternate means. This time may be inaccurate in that some crews may anticipate the need to switch to alternative shutdown or abandon the MCR and do it earlier and others may be reluctant and stay longer. However, which assumption is 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 switchover to a RSP or use alternate shutdown means will have to be taken in to account. This time would need to be subtracted from the time available to perform the remaining actions.[6]

Two other issues also arise. If there is reason to believe that the crews would abandon early, then the potential difficulties associated with performing the remaining actions outside the MCR would have to be taken in to account in their quantification. Similarly, if there is reason to believe the crews would abandon sometime after the point at which control would be lost or the MCR would be assumed to be uninhabitable, then (as noted above) this time would have to be subtracted from the available time. 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.

5.2.10 Guidance for Using the SPI Flowchart for EOC or EOO Due to Spurious Instrumentation (Figure 5-6)

The flowchart presented in Figure 5-6 (SPI) addresses the assignment of HEPs for the failure to recover an EOC or EOO committed due to response to spurious instrumentation (due to fire effects). Upon entry into the flowchart, it is assumed that the EOC or EOO has been committed (a HFE has been modeled to address the potential error) and the flowchart then assesses the probability that this error would remain uncorrected (i.e., operator recovery of the EOO or EOC fails).

In order to quantify the recovery of EOCs or EOOs due to 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., RPV level, SG level) is required for a fire manual action, then the cable routing may be known prior to fire PRA analysis. In many cases, the fire procedures specifically tell the operator which trains of instrumentation (identified as protected or available by the fire protection program) are available given the location of the fire.

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[6] Note that in practice, precise estimates of when the crews would decide to abandon the MCR or begin to use alternate shutdown are not believed to be critical for the scoping analysis. 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 document, but trying to precisely anticipate when operating crews will decide to abandon the MCR etc. in these conditions may not always be realistic. It is assumed that operating crews will respond to the conditions they are facing 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 impreciseness in estimating the related timing.

However, there are HFEs required for fire PRA which are not required for the deterministic safe shut down analysis (either Appendix R or NFPA-805). 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 in order to credit this action. If the cables for RWST level indication are routed through the fire area in question, then EOOs and EOCs due to spurious indicators need to be considered. If the cables are not routed through this room, then EOOs and EOCs do not need to be considered. If the instrumentation is not required for a deterministic safe shutdown action then it can be assumed that it is not protected by a fire barrier wrap.

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 per 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 to direct flame impingement, 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 the purposes of this scoping fire HRA guidance, if a plant has such a list that is to be used in fire scenarios, then 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 those situations in which the instrument in question is listed as being suspect due to the location of the fire. If, however, the HRA analyst feels that due to other circumstance that might cause the operator to ignore this warning and might, therefore, commit the error anyway (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.

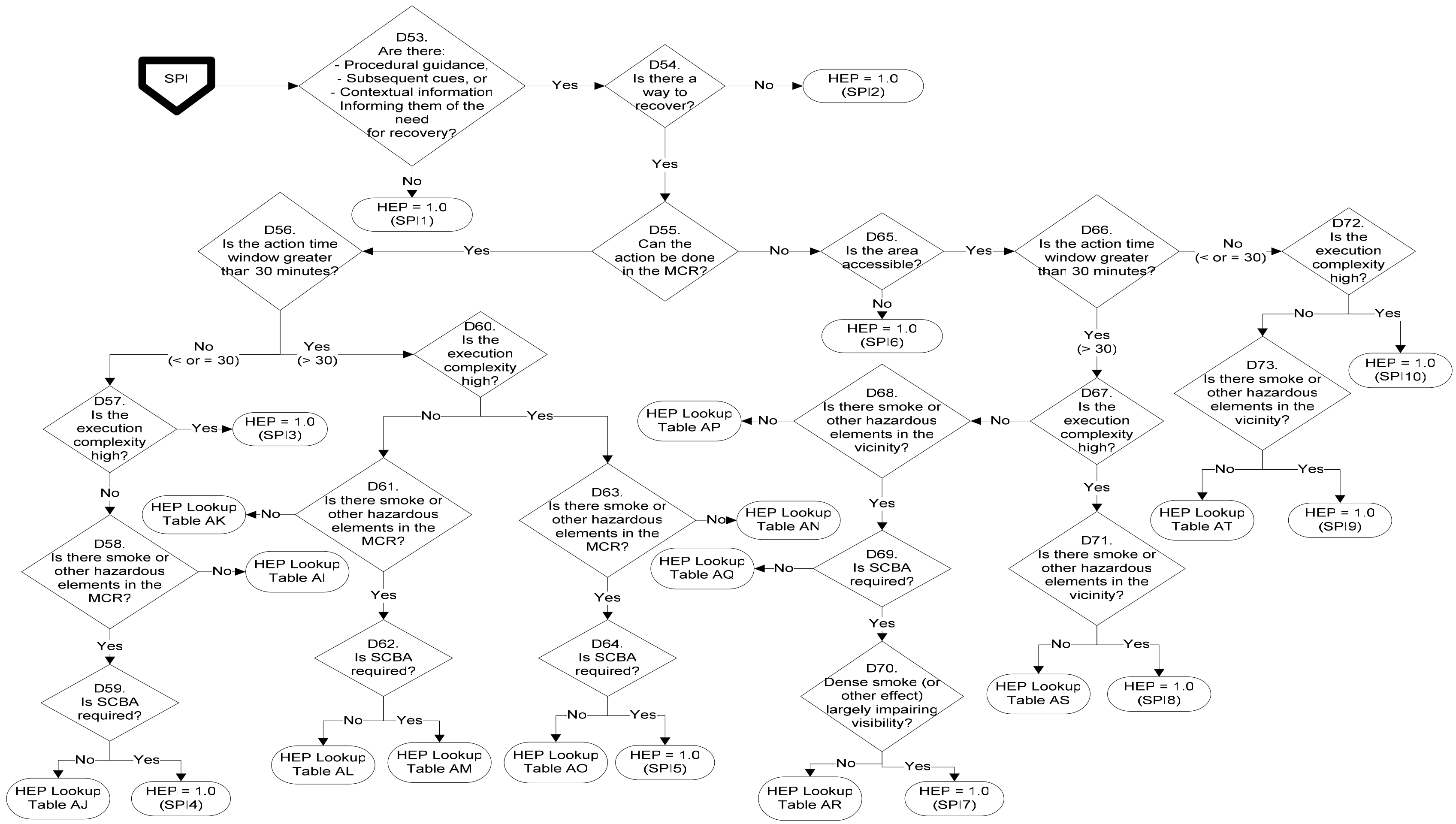


Figure 5-6
SPI - scoping HRA analysis for EOC or EOO due to spurious instrumentation

Following the assumption that the operator would commit an EOC or an EOO due to a spurious indicator, Figure 5-6 quantifies the probability of recovering this error. The initial question asked upon entry into Figure 5-6 inquires if there is information available to help the operators recognize the need to recover the error (D53). Recovery of the error may be through:

- Reversal of the action or the use of an alternative system, for the committal of an EOC, or
- Performance of the necessary action, if an EOO had been committed.

The signs directing the operator to the need to recover may be through procedural guidance or through subsequent (especially, 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 due to 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 of a great enough strength (compelling) to enlighten the operator that the situation must be remedied (e.g., a compelling alarm). Especially if the operator was following procedural guidance when responding to the spurious indicator, it will be his or her predilection to believe the action was necessary and to 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 such that the operator would be made 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 means 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, it may not be possible. Therefore, the availability and feasibility of the recovery action should be ensured before progressing further (D54).

Given the recovery action can be done, the next decision point is the location of the action (D55). If the action is performed within the MCR, the analyst is pointed one direction in the flowchart, and is pointed the other direction if it is a local action. At this point, the quantification proceeds similarly to what was done in the quantification of in MCR actions (Figure 5-3) and ex-CR actions (Figure 5-4). For in MCR actions, a series of questions is asked to determine the action time window, level of execution complexity, the level of smoke, heat, or other toxins, and the need to wear breathing gear (e.g., SCBA). For more discussion on how each of these is considered refer to section 5.2.4.

For ex-CR actions, the first issue is to ensure that the area in which the action takes place as well as the travel path to the area are accessible (D65). If this is not the case, the action is assumed to fail (HEP = 1.0). Assuming the area and travel path are accessible, the analyst must work through a series of question similar to those asked for in MCR actions. Specifically, the analyst needs to determine the length of time in the action window, the level of execution complexity, the level of smoke, heat, or other toxin at the site of the action, and the need to wear breathing apparatus (e.g., SCBA).

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

Table 5-5
EOC or EOO due to spurious instrumentation HEP lookup tables

HEP Lookup Table	Time Margin	HEP	HEP Label
AI	≥ 200%	0.25	SPI11
	< 200%	1.0	SPI12
AJ	≥ 200%	0.5	SPI13
	< 200%	1.0	SPI14
AK	≥ 100%	0.05	SPI15
	50 – 99%	0.25	SPI16
	< 50%	1.0	SPI17
AL	≥ 100%	0.1	SPI18
	50 – 99%	0.5	SPI19
	< 50%	1.0	SPI20
AM	≥ 100%	0.2	SPI21
	< 100%	1.0	SPI22
AN	≥ 200%	0.25	SPI23
	< 200%	1.0	SPI24
AO	≥ 200%	0.5	SPI25
	< 200%	1.0	SPI26
AP	≥ 100%	0.1	SPI27
	50 – 99%	0.5	SPI28
	< 50%	1.0	SPI29
AQ	≥ 100%	0.2	SPI30
	< 100%	1.0	SPI31
AR	≥ 100%	0.4	SPI32
	< 100%	1.0	SPI33
AS	≥ 200%	0.5	SPI34
	< 200%	1.0	SPI35
AT	≥ 200%	0.5	SPI36
	< 200%	1.0	SPI37

5.3 Detailed HRA Quantification

As discussed above, 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 that which could be developed using one of the two detailed HRA approaches described in this report.

For those 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:

- The EPRI HRA approach [2] presented in Appendix C of this report, or
- The ATHEANA HRA method (NUREG-1880) [3] presented in Appendix D.

With appropriate consideration of the fire context as described in Section 4 of this report (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 time 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 [8] provides general insights on the strengths and weaknesses of HRA methods for non-fire conditions.

5.4 Special Cases where Little or No Credit should be Allowed

In Section 12.5.5.3 of NUREG/CR-6850 [1], several cases were discussed where it was recommended that little or no credit be taken for human actions. These cases were identified prior to the efforts described in this document to develop more detailed HRA quantification processes. Although the conditions addressed in these special cases should still be carefully analyzed, a detailed HRA analysis may identify situations where it could be appropriate to take some credit for such actions. The discussions of PSFs presented in this report generally address the issues associated with these cases, but since they were explicitly called out in NUREG/CR-6850 [1], they are revisited here to avoid confusion. Each of the special cases from NUREG/CR-6850 [1] is presented below, followed in italics by relevant caveats.

- Tasks needing significant activity and/or communication among individuals while wearing SCBAs. It is believed that communication under such conditions is very difficult, and until proven otherwise, where the levels of smoke, heat, or toxic gases are high enough to necessitate the use of SCBAs, the likelihood of success is assumed to be extremely low. Additionally, 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: It is the case that some 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. For any of the above situations, a realistic demonstration that the actions can be performed under similar conditions would provide good justification.

- The fire could cause significant numbers of spurious equipment activations (and/or stops) and affect the reliability of multiple instruments. Actions that are based on such instruments and equipment should be assumed to fail, unless alternate sources of reliable information can be documented and a basis for using the alternate sources can be strongly supported. The additional time, complexity, availability of procedures, and other relevant PSFs contributing to identifying and using the alternate 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 and 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 alternate routes are possible, the demands associated with identifying such routes and any extra time associated with using the alternate routes should be factored into the analysis.

  Caveat: None

- Actions needing the use of equipment that could have been damaged such that even manual manipulation may be very 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

- Actions to be performed without the basic needs of procedure direction, training, special tools (if necessary), or sufficient time should not be credited.

  Caveat: None

5.5 References

1. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*. September 2005. NUREG/CR-6850/EPRI 1011989.
2. Software Users Manual, “The Human Reliability Calculator Version 4.0, EPRI, Palo Alto, CA, and Scientech , Tukwila, WA. Product ID. 1015358”, January 2008.
3. NUREG-1880, “ATHEANA User’s Guide”, June 2007.
4. ASME RA-S-2000, “Standard for PRA for Nuclear Power Plant Applications”, Rev 14A, May 11, 2001 supplemented by ASME RA-Sa-2003, “Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications”, December 5, 2003, supplemented by ASME RA-Sb-2005, “Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications”, December 2005, all by American Society of Mechanical Engineers.
5. NUREG/CR-6776, “Cable Insulation Resistance Measurements Made During Cable Fire Tests”, June 2002.

6. BSR/ANS 58.23 “FPRA Methodology Standard”, December 2006 (Note).

   Note: These Fire HRA Guidelines were originally written to the December 2006 draft version of the Fire PRA Methodology standard which ultimately became ANSI/ANS-58. 23-2007 in November 2007. Some sections also cite ASME PRA-S-2000, “Standard for PRA for Nuclear Power Plant Applications”, and its addenda ASME RA-Sa-2003 and ASME RA-Sb-2005, as they relate to internal events PRA issues that apply to Fire PRA/HRA. It was decided to issue this version of the Fire HRA Guidelines for public review and comment rather than delay it further to resolve any inconsistencies between the draft and final versions of the ANS standard, or to review and incorporate information from the recently published ASME/ANS RA-S-2008, “Level 1 and Large Early Release Frequency (LERF) PRA Standard”, which applies to at-power internal events, internal fire events, and external events for operating reactors. The necessary reviews and revisions to reflect the latest standards will be addressed prior to issuing the final Fire HRA Guidelines.

7. NUREG-1852, “Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire”, October 2007.

8. NUREG 1842, “Evaluation of Human Reliability Analysis Methods Against Good Practices”, August 2006.

6 RECOVERY

6.1 Introduction

New recovery actions are needed for development and evaluation of realistic fire PRA models at different stages of development (e.g., 7b and/or Task 11 of NUREG/CR-6850 [1]). For fire HRA, recovery actions are modeled in the PRA the same way as in the internal events HRA. The ASME PRA standard [3] permits the modeling of recovery actions that have cues, procedures, and are feasible. The main difference for a fire HRA is to consider the impact of the fire on the ability to perform recovery actions associated with specific fire scenarios.

The objective of this section is to provide guidance on how recovery actions can be modeled in the post-initiator fire HRA and provide requirements that should be met before applying recovery actions with an HEP less than 1.0.

There are two types of recovery actions of concern for fire HRAs that are discussed in this section. These are:

- Type 1 – Recovery from a human error, which is treated in the evaluation of the basic HEP Typical recovery activities that are considered in the HEP include peer checking, unexpected instrument responses in response to an action, and new alarms. These apply in both the internal event and fire HFE evaluations.
- Type 2 – Recovery of initially unavailable functions, systems, or components needed to achieve successful decay heat removal and limit power input from the core, which are treated by developing a new HEP and evaluating dependencies with other HFEs in the sequence. This is consistent with the standard PRA concept of recovering cutsets, and those cutsets may contain either equipment or human elements. Recovery in this sense means that a new human action is added to the sequence to mitigate the problem.

Another recovery action (Type 3) that is considered in the PRA involves modeling the fire brigade and their actions to extinguish the fire. According to NUREG/CR-6850 [1], this type of recovery action is treated in the fire modeling task via 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 Core Damage Frequency PRA model.

The approach for recovery in Screening is to assume that recoveries of Type 1 are included in the HEP assessment and if Type 2 assessments are needed, they should be performed within the rules of the Scoping analysis or evaluated as part of a detailed assessment.

The recovery approach for Scoping implicitly addresses Type 1 recovery in the HEP assignment as outlined by the scoping trees and Type 2 with new defined actions that are allowed by requirements for the scoping trees.

The scoping approach does not address complex recoveries associated with MCR evacuation, dealing with spurious multiple actuations, spurious multiple instrument cues, or remove and restore power on buses and circuits. These recoveries require a detailed analysis.

6.2 Identify and Define

After the initial fire PRA model quantification, recovery actions may be identified to restore or reconfigure a function, system or component initially unavailable in that scenario to reduce its likelihood by the probability of a successful recovery. The need for recovery actions can follow from PRA model iterations with a screening, scoping or part of a detailed analysis. The identification of the recovery actions not only includes the definition, but also includes a preliminary feasibility assessment consistent with that discussed in Section 3.

The need for the recovery is determined by the dominance of the sequence or cutset and the feasibility is determined by the nature of the recovery action postulated. The analyst must first determine which sequences or cutsets should be considered for inclusion of recovery actions. The selection of the number of contributors is a balance between the contribution of the specific sequence to core damage frequencies and the analytical effort needed to identify and quantify the recovery action. For fire PRA, to ensure all potential recoveries are modeled, in addition to cutset review, there should also be review of the procedures and talk-throughs with operators or training personnel to include potential recovery actions that have not been previously identified.

In terms of feasibility, Type 1 recovery activities that are considered in the HEP itself include an evaluation of the likelihood and efficacy of peer checking of other operator actions, and response vs. complacency regarding new alarms. Feasible Type 2 recovery actions require a cue (instruments or procedure), a procedure for actions, and sufficient time, tools and staff to carry out the recovery action. It is assumed that repair of equipment is not allowed in recovery actions, but realignments, manual starts and breaker operations are allowed. These Type 2 recoveries can be modeled in fault trees, event trees, or as cutset events.

6.2.1 Recovery Action Requirements

The identification of a recovery action must meet specific requirements. From NUREG-1792 [2] the following requirements need to be considered when incorporating a recovery action into the PRA model:

- whether the cues will be clear and provided in time to indicate the need for a recovery action(s), and the failure that needs to be recovered
- the recovery is not a repair action (e.g., the replacement of a motor on a valve so that it can be operated)
- whether sufficient time is available for the recovery action(s) to be diagnosed and implemented to avoid the undesired outcome

- whether sufficient crew resources exist to perform the recovery (recoveries)
- whether there is procedure guidance to perform the recovery (recoveries)
- whether the crew has trained on the recovery action(s) including the quality and frequency of the training
- whether the equipment needed to perform the recovery (recoveries) is accessible and in a non-threatening environment (e.g., extreme radiation or smoke)
- whether the equipment needed to perform the recovery (recoveries) is available in the context of other failures and the initiator for the sequence/cut set

6.2.2 Limits on use of Recovery Actions

In accordance with ASME standard requirement HR-H2 [3] recovery actions should only be modeled as a frequency reduction for a fire scenario 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.
- "Cues" (e.g., alarms) that alert the operator to the recovery action provided procedure, training, or skill of the craft exists.
- Attention is given to the relevant performance shaping factors provided in HR-G3.
- There is sufficient manpower to perform the action.

Additionally, NUREG/CR-6580 [1] states that the following actions should not be recognized in the fire PRA.

- Recovery actions that require significant activity and or communication among individuals while wearing SCBAs. It is believed that communication under such conditions is very difficult, and until proven otherwise, where the levels of smoke, heat, or toxic gases are high enough to necessitate the use of SCBAs, the likelihood of success is assumed to be extremely low. Additionally, 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.
- Recovery actions that would require the operators or other personnel to travel through fire areas should not be credited. Where alternate routes are possible, the demands associated with identifying such routes and any extra time associated with using the alternate routes should be factored into the analysis.
- For internal events HRA recoveries of systems or components previously assumed failed are typically not credited. Similarly, for fire PRA recovery actions that involve restoring systems or equipment damaged by the fire should not be credited.
- Recovery actions that are not proceduralized or for which there is insufficient time should not be credited.

NUREG-1852 [4] states that recoveries should only be recognized for scenarios in which there is a time margin available for the action to account for potential unexpected fire effects.

6.2.3 Recovery Action Feasibility Factors

After the recovery actions have been identified a check addressing the feasibility must be performed. SHARP1 [5] requires the following conditions be met in order for the action to be considered feasible:

- The MCR crew must be able to diagnose the need for recovery.
- The time to accomplish the task must be adequate considering the total time available.
- The required equipment is available to the crew and the crew can gain access to the equipment.
- There must be enough available staff to perform the action.

For fire HRA the following conditions, based on PSF considerations, must be addressed in order to assess the feasibility of the recovery action:

- **Cues and Indications –** The MCR crew must be able to diagnose the need for the recovery action. The instrumentations and indications needed for diagnoses must not be affected by the fire.
- **Timing –** 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. The time must address the timing impacts due to fire (see PSF section on timing). Since most recovery actions occur in combinations with other HFEs, a time line is needed that accounts for early success or failures in other actions and that demonstrates adequate time available for the recovery action.
- **Procedures and Training** – Based on the recommendation in the ASME Standard [3], only proceduralized actions can be credited for recoveries. Recovery actions may be proceduralized in specialized procedures which the operators may not receive extensive training for the specific case being analyzed. Identifying the specialized procedures may require discussions with operations personnel. For example, cross-tying the RWST in the event of drain down due to multiple spurious operators may not be specifically addressed in the fire procedures, but there may be a procedure addressing RWST cross-tying in the event of an external event and the training on this event could be extensive.
- **Human-Machine Interface** – Similar to internal events recovery actions the fire HRA can not include repair of a system or component. For fire HRA, repair of components or systems damaged due to fire should not be included as successful in the fire PRA. For local actions the diagnosis and planning for the recovery action is performed in the MCR and there is no additional diagnosis required in executing the procedure at the local station (e.g., open a valve, close a breaker, or regulate flow).
- **Environment** – Actions that are “heroic” (e.g., operators must enter an extreme high-radiation environment in order to perform) should not be included in the analysis. For fire HRA, heroic actions would include working in or traveling through a location where the fire or heavy smoke is present.

- **Special Equipment** – If the recovery action requires special equipment such as hoses, ladders, or other off-site tools, then additional time for locating these items should be accounted for in the recovery action. In addition, there must be ample time available for the crew to locate and setup the special equipment.
- **Specific Fitness** – If the recovery action requires that the crew wear SCBAs or fire protection gear, the actions should not be included in the fire PRA. Additionally, no credit should be given for recovery actions in which not all able bodied operators could perform.
- **Availability of staff** – There must be enough crew available to complete the recovery action. In addressing the availability of the crew, other competing actions should be identified and the recovery action can only be credited if there is ample crew for all competing tasks as well as the recovery.
- **Communications** – Recovery actions that require significant activity and or communication among individuals while wearing SCBAs should not be credited. Communications under such conditions is very difficult, and until proven otherwise, where the levels of smoke, heat, or toxic gases are high enough to necessitate the use of SCBAs, the likelihood of success is assumed to be extremely low.

In addition to the specific PSFs mentioned above, all other PSFs outlined in Section 5 need to be considered in the recovery analysis in the same manner as the initial HFE.

6.3 Quantification

The quantification should follow the same approach as outlined in Section 5. However, because of the potential complex nature of recovery actions in many cases, demonstrating the feasibility of the actions per the guidance above and ensuring an adequate time margin are especially important. In many cases, a detailed HRA may be required using either the ATHEANA or EPRI method within the constraints discussed above.

Type 1 recovery from a human error is modeled as part of the HFE quantification by adjusting the HEP within the time constraints of the event that is modeled. These recovery actions may be identified and quantified as part of the initial HFE definition or in the quantification stage because of the close connection with other HFEs.

Another option for quantification of recovery actions is to apply plant specific data. The data must be applicable for the plant/sequence context or modified accordingly. For example, a plant may use available experience data for the probability of failing to align a firewater system for injection, but the experience data is based on designs for which all the actions can be taken from the main control room whereas for this plant, the actions have to be performed locally (NUREG-1792 [2]). Therefore, the time margin for performance of the action would have to be increased, and consideration would have to be given to performance shaping factors that would relate to fire-related effects at the local control site (e.g., environmental conditions, wearing of special gear, and accessibility) as discussed in Appendix H.

For quantification, the ASME PRA standard [3] requires that dependencies between recovery actions and any other HFEs in the sequence, scenario or cutset be addressed. To account for these dependencies, follow the guidance in Section 8.

6.4 References

1. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities.* September 2005. NUREG/CR-6850/EPRI 1011989.
2. NUREG-1792, "Good Practices for Implementing Human Reliability Analysis (HRA)", Sandia National Laboratories, 2005.
3. ASME RA-S-2000, "Standard for PRA for Nuclear Power Plant Applications", Rev 14A, May 11, 2001 supplemented by ASME RA-Sa-2003, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 5, 2003, supplemented by ASME RA-Sb-2005, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 2005, all by American Society of Mechanical Engineers.
4. NUREG-1852, "Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire", October 2007.
5. *Systematic Human Action Reliability Procedure (SHARP) Enhancement Project. SHARP 1 Methodology Report.* December 1992. EPRI TR-101711.

7 DEPENDENCY ANALYSIS

The analysis of dependent HFEs is important, because risk metrics such as core damage frequency can be significantly underestimated in cutsets or sequences containing multiple Human error probabilities (HEPs). The ASME standard [1] requires that multiple human actions in the same accident sequence or cutset be identified, an assessment of the degree of dependency is performed, and a joint human error probability be calculated. For fire PRA, a preliminary dependency analysis is preformed in combination with NUREG/CR-6850 [2] Detailed Fire Modeling Task 11 and is finalized as part of Task 14, Fire Risk Quantification.

This section is concerned with identification of dependencies among HFES at the cutset level that have been up until this point 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 scoping or detailed HRA quantification.

7.1 Qualitative Dependency Analysis

Through a review of cutsets and sequences, the combination of multiple sets of HFEs are identified for potential dependencies. Once the cutsets or sequences are identified they should be reviewed as follows:

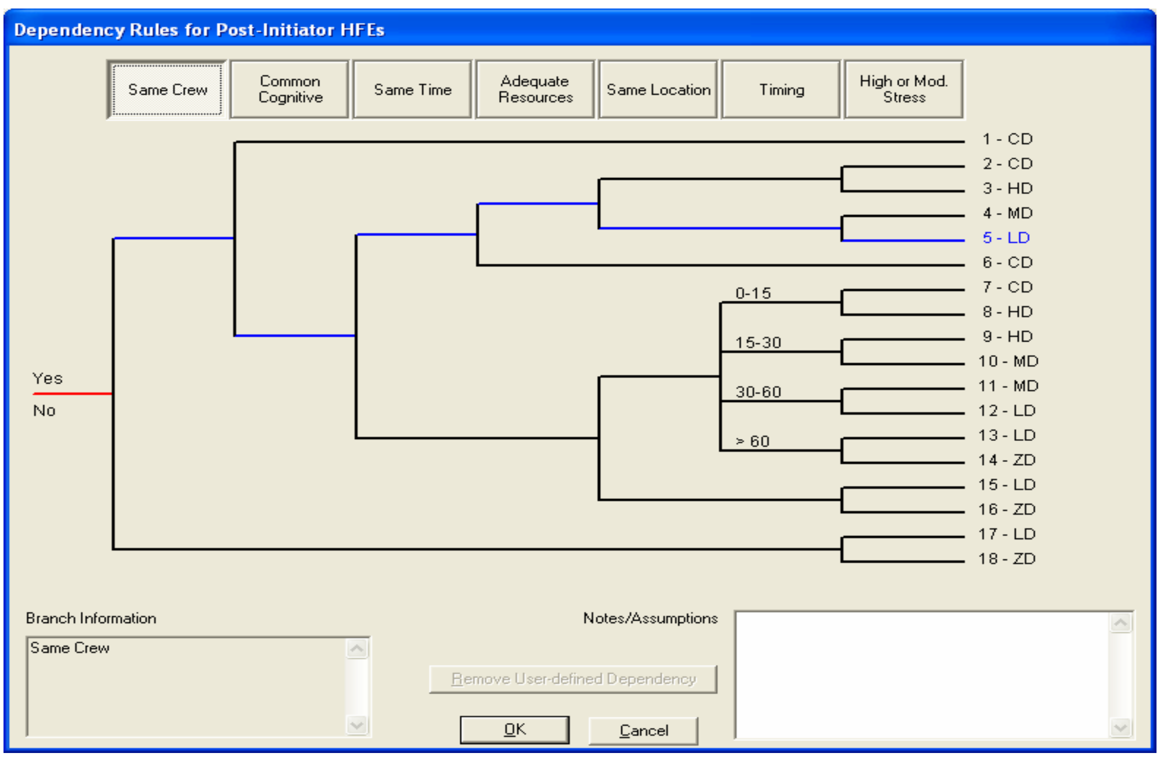
- The review should ensure that sequences or combinations of operator actions do not exist where the joint human error probability is less than a lower limit such as 1E-5.
- The review should ensure no accident sequences with multiple human actions were prematurely truncated.
- Dependencies that have been previously accounted for the in the internal events HRA, need to be re-evaluated for fire HRA. There may be cases where the assumptions about dependencies may no longer be credible in the fire PRA. For example, if the Fire procedures are implemented in parallel to the EOP, new dependencies may be created due to performing multiple actions in the same time period, possibly with the same staffing levels. Additionally, changes in timing due to fire impacts could affect workload and stress levels, for example.
- An assessment of the feasibility of multiple HFEs 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 HFE as an independent action, which could be the case if the HFE is a fire manual action, there is the potential to not have enough crew available to perform all HFEs in the sequence. Additionally, there may be enough time perform each HFE independently but in combination, there is not enough time 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, it is also important to review successful operator actions that occur in the same sequence. The success paths would be identified by review of the event trees, and should be noted in the HFE definition, in accordance with ASME criteria HR-F2 requirement B [1].

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 Standard [1], influences of success or failure on parallel and subsequent human actions and system performance should include:

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

Once the combination of HFEs is identified a level of dependency is assigned. One approach to assigning a level of dependency is shown below and taken from the EPRI detailed HRA methodology [3]. This decision tree is based on discussion presented in THERP. Both internal events HRA and fire HRA evaluate the same elements in the dependency analysis.



Same 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 different crew. In this case, the "No" branch on the "Same Crew" decision node in Figure D-1 is selected. The different crew can be considered independent as the shift change will involve a complete re-evaluation of the plant status, so ZD can be assigned for low stress [1] situations (S18). 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 where the HFE time window is longer than the length of a shift.

Common 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 "Common Cognitive" decision node is selected as a first approximation, as these HFEs would be regarded as completely dependent. The analyst should determine if the common cognitive element had been modeled as a separate basic event. If the common cognitive element is modeled as a separate basic event, the "No" branch can be selected.

Same Time – If the cues for two HFEs occur at the same time, the "Yes" branch on the "Same Time" 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 illustrated below, the "Yes" branch on the "Same Time" decision node in Figure D-1 is also selected, as the required actions would have to be performed either simultaneously, or the crew may select to do either one or the other based on some prioritization. These HFEs are termed "Simultaneous" HFEs:

Adequate Resources – For simultaneous HFEs, the next consideration is whether there are sufficient resources to support the required actions. This determination can be done by comparing the required tasks with the number of crew (workload). If the resources are inadequate, the "No" branch on the "Adequate Resources" 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 "Same 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 "Same Location" decision node is selected. (Location refers to the room or general area where 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). For high or moderate stress scenarios, assign moderate dependence; for low stress, assign low dependence.

Same Location – If the execution for the HFEs occur in the same location then the dependency level is either high or complete, if the actions are performed in different locations then the dependency level is either moderate or low.

Timing – The timing decision branch considered 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 may include preceding functional failures and successes, preceding operator errors or successes, availability of cues and appropriate procedures, workload, environment (heat, humidity, lighting, atmosphere, and radiation), requirement and availability of tools or parts, 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 closer they get to exhausting procedural options, the higher the stress.

With the proper level of dependency identified, the dependent HEPs can be re-assessed by applying the appropriate dependency formulas in Table 10-17 and shown below in Table 8-1 in THERP [3] or, if ATHEANA [5] is being used to quantify the actions, appropriately documented expert judgment can be used (as described in NUREG-1880 [4]). The effects of the revised, dependent HEPs are typically incorporated by applying correction factors to PRA such as revising probabilities to be conditional events or using rule-based recovery probabilities. Once the dependency evaluation has been conducted, then the incorporation of the human interaction into the PRA model may require revision. However, some HRA methods, such as ATHEANA, use a different approach to address dependencies. For example, ATHEANA explicitly models both the initial HFE and the non-recovery event together, on a cutset-by-cutset basis.

Table 7-1
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

7.2 Screening and Scoping HEPs

A review of the cutsets for dependencies will show some combinations in which there are both screening and scoping HEPs. The screening HEPs by definition, are considered conservative and adjusting these HEPs even more 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 HFEs is shown to be feasible. (There is enough time to complete all the actions and enough crew members are available to complete all the actions.) Scoping HEPs can be treated using the same approach as described in the section above, 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 that the actions are feasible and there is an adequate time margin given the dependent effects.

7.3 References

1. ASME RA-S-2000, "Standard for PRA for Nuclear Power Plant Applications", Rev 14A, May 11, 2001 supplemented by ASME RA-Sa-2003, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 5, 2003, supplemented by ASME RA-Sb-2005, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 2005, all by American Society of Mechanical Engineers.
2. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*. September 2005. NUREG/CR-6850/EPRI 1011989.
3. Software Users Manual, *The Human Reliability Calculator Version 4.0.* EPRI, Palo Alto, CA, and Scientech, Tukwila, WA: January 2008. Product ID. 1015358.
4. 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.
5. NUREG-1624, Rev 1, Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA)", May 2000.

8 UNCERTAINTY ANALYSIS

8.1 Background

Uncertainty in the context of PRA and HRA is defined as the representation of the confidence in the state of knowledge about the parameter values and models used in constructing the PRA (ANSI/ANS-58.21-2007 [1] and ASME RA-2002/RA-Sb-2005 [2]). For fire HRA, uncertainties are addressed in the same manner as for internal events HRA. The ASME standard [1] requirement HR-G9 specifies that the HRA characterize the uncertainty in the estimates of the HEPs consistent with the quantification approach, and provide mean values for use in quantification.

The consideration and assessment of uncertainty in any analytical context is typically performed to assist the decision-making process that the analytical PRA models support. In fire modeling and HRA in particular, by identifying the areas of uncertainty and focusing on those aspects of uncertainty that can be reduced, the associated decision-making processes can be improved. Based on a review of many applications, the common characteristics and distinctions of uncertainty are:

- Uncertainty versus randomness
- Aleatory versus epistemic
- Parametric, modeling and completeness
- Sensitivity analysis versus uncertainty analysis

8.1.1 Uncertainty Versus Randomness

Although most PRA applications do not distinguish between these two, the term randomness refers to the inherent variability of an outcome that is limited by imperfect knowledge regarding the modeled phenomena and the models and parameters used in the modeling.

8.1.2 Aleatory Versus Epistemic

Aleatory uncertainty is attributed to inherent randomness, natural variation, or chance outcomes in the physical world; in principle, this uncertainty is irreducible because it is assumed to be a property of nature. Aleatory uncertainty is sometimes called random or stochastic variability.

Virtually all PRAs of current generation plants identify some potentially risk important operator actions. The baseline uncertainty assessment includes variability based on factors such as: safety culture, organizational performance, communication and interface among groups, and operating crew factors such as normal differences in crew variability, personalities, and time of day (circadian rhythms). All of these are assumed to be independent of the fire event context.

Thus, evaluation of the aleatory uncertainty provides a parameter for estimating the uncertainty bounds around the mean HEP. This parameter represents the irreducible uncertainty based on the elements of personnel human behavior that are outside the event-driven context of a fire scenario.

Epistemic uncertainty is attributed to the lack of knowledge about events and processes; in principle, this uncertainty is reducible because it is a function of information. Epistemic uncertainty is sometimes called, subjective or internal uncertainty, and divides into two major sub-categories: model uncertainty and parameter uncertainty. When combined with the aleatory uncertainty, the epistemic uncertainty parameters provide a basis for quantitatively estimating the uncertainty bounds for a specific HEP. The combined uncertainty parameters represent both the irreducible and event driven issues associated with the fire scenario. When combined with the aleatory uncertainty, the epistemic uncertainty parameters provide a basis for quantitatively estimating the uncertainty bounds for a specific HEP. The combined uncertainty parameters represent both the irreducible and event driven issues associated with the fire scenario. This uncertainty contribution comes from the knowledge of the analyst integrating the information about the fire context and determining the likelihood of an operator error that can lead to core damage. As information about the fire context and effects, and the operators expected actions according to the procedures increases for the HRA analyst the epistemic uncertainty decreases.

8.1.3 Parametric, Modeling and Completeness

PRA applications have used uncertainty in parameters, modeling and completeness to represent the lack of knowledge or primarily the epistemic uncertainty associated with specific applications.

8.1.3.1 Parameter Uncertainty

Parameters address uncertainties associated with failure rate data, HEP estimates, applicability of data, statistical variation, model processing simplifications and truncations.

The error factor (EF) is used to describe the statistical variation of uncertainty in the measure of the HEP. It is defined as the ratio of the HEP0.95 to HEP0.50 values of a distribution of HEPs. The mean of a lognormal distribution can be estimated using the median and the EF using this equation: median * $\exp\{0.5[(\ln EF)/1.645]^2\}$.

In chapter 7 of NUREG/CR- 1278 [3] Swain uses data collected by Wechsler to measure the ratio of the upper and lower bounds of typical repeated tasks by people with aptitude and training on the task, as shown in Table 8-1. The ratio of the upper and lower bound extremes, in these data measures, range from 1.76 to 2.83 (e.g., the $_{time}0.95$ to $_{time}0.50$. values). Thus, when converting the end point range to an EF for a lognormal distribution, the EF ranges from 1.33 to 1.68 in the tasks where data were collected (Table 7-1 in NUREG/CR-1278 [3]). Using these data to address normal human variability (aleatory) for typical tasks in less repetitive conditions in a nuclear plant and assuming that the rate of actions measured has the same distribution as the human error rate (lognormal), Swain assigned an EF of 3.0 as the generic HEP uncertainty. This encompasses all the sources of uncertainty in a task defined in the PRA to be evaluated (aleatory plus epistemic). If the event context increased the stress, or the HEP was much less than .001, then Swain recommended an EF of 10.0 on the HEP. Thus, it can be considered that aleatory variability accounts for less than 2 of the error factor and epistemic the remainder of 3, 5, or 10.

Table 8-1
Summary of measurements used to evaluate HEP uncertainty in NUREG/CR-1278 [3]

Task	unit of measure	Subjects	Comments	Mean	Upper extreme	Lower Extreme	Ratio upper to lower extreme	EF upper to middle (lognormal)	Ratio Mean to median	Calculated median (lognormal)
Filament mounting (elec. Bulbs)	Ave. per hour	100		104.9	132	75	1.76	1.33	1.01	103.36
Card punching	Ave # Cards per hour	113	day shift	232.2	340	160	2.13	1.46	1.03	226.19
Assemble radio Tubes	# tubes per hour	65		99.5	132	61	2.16	1.47	1.03	96.80
Checking posting and listing	Percent of average	34	females	102.1	150	65	2.31	1.52	1.03	98.85
Card punching	Ave # Cards per hour	121	night shift	198.5	275	115	2.39	1.55	1.04	191.65
Check grocery store orders	Time in seconds	46		365	575	225	2.56	1.60	1.04	350.45
Machine sewing	Units per hr. 5 day ave	101	females	72.4	112	43	2.60	1.61	1.04	69.40
Manipulate lathe	Avg. output per day	120		71.8	134	51	2.63	1.62	1.04	68.77
Typing	Words per minute	616		53.4	85	30	2.83	1.68	1.05	50.79

Assumptions
People tested had aptitude for the task and were trained.
The highest score is rarely 5 times the lowest score and usually not more than three.
The log normal distribution was a better fit to the data than a normal distribution.
No reason to think the log normal is not appropriate for HEPs as well as timing data.
Mean/median = exp $\{0.5[(\ln EF)/1.645]^2\}$

8.1.3.2 Modeling Uncertainty

Modeling addresses the adequacy of detail in logic modeling, logic correctness and recognition of dependencies in the model inputs.

One way that modeling uncertainty is addressed in the HRA Guidelines methodology is through the questions in the scoping analysis process which strive to reduce areas of uncertainty that are not addressed in the screening process. For example, the scoping question “Given when the cues occur, is the action still feasible?” requires a demonstrated feasibility of the action via job performance measures considering the time required to do the task and time allowed by the system.

Each subsequent question reduces modeling uncertainty as more information is obtained. For example, with inputs from electrical evaluations, a "Yes" answer to “All necessary & sufficient cues & controls for required actions are not impacted by fire?” reduces uncertainty assumed in the screening assessment. Thus, changes can be made from an unknown No to a sure Yes as information on the location of train power and instrument cables is obtained. This reduces key modeling uncertainty about the cue for required actions involving cooling train circuitry. The subsequent level of information obtained by verifying the location of circuits that cannot be impacted by the fire addresses the elimination of potential spurious actions and indications (See Appendix B examples).

Likewise answering the following scoping questions about managing the fire event reduce uncertainty.

- Within the main control room (MCR), do the procedures match the scenario?
- Is the action to be performed in the MCR or locally?

Areas that contribute to increased uncertainty should be addressed in the detailed analysis. For example, events that involve MCR abandonment actions are typically plant specific and may not have clear decision criteria for abandonment. When habitability is not an issue, crew may not completely abandon MCR even if their ability to control parts of the plant are hindered due to fire effects on control cables, in performing demonstrations of time-authenticated actions, involving diagnosis and execution, times need to be estimated and there are a number of activities that may influence time to respond and contribute to task timing uncertainty. Situations or factors in the fire context that may be very difficult to recreate in simulations and job performance measures include:

- MCR staff obtaining correct fire plan and procedures once fire location is confirmed
- MCR staff knowing that special instructions to responsible local staff need to be provided
- Local staff collecting procedures, checking out communications equipment and obtain any special tools or personnel protective equipment necessary to perform actions at a local control station
- Traveling to necessary locations through smoke
- MCR staff alerting and/or communicating with local staff implement coordinated or sequential actions in multiple locations

- Dealing with difficulties such as problems with instruments or other equipment (e.g., locked doors, a stiff hand wheel, or an erratic communication device). The PRA hardware models typically address these issues, unless no manual actions are modeled.

8.1.3.3 Completeness uncertainty

Reg. Guide 1.174 [4] states that "Completeness is not in itself an uncertainty, but a reflection of scope limitations. The result is, however, an uncertainty about where the true risk lies. The problem with completeness uncertainty is that, because it reflects an unanalyzed contribution, it is difficult (if not impossible) to estimate its magnitude. Some contributions are unanalyzed not because methods are not available, but because they have not been refined to the level of the analysis of internal events. Examples are the analysis of some external events and the low-power and shutdown modes of operation. There are issues, however, for which methods of analysis have not been developed, and they have to be accepted as potential limitations of the technology. Thus, for example, the impact on actual plant risk from unanalyzed issues such as the influences of organizational performance cannot now be explicitly assessed." Completeness is addressed through the review process to either expand upon the original analysis or to provide justification for scope constraints.. The risk-informed process described in RG 1.174 includes defense-in-depth, safety margins, and performance monitoring to provide protection against the unknown elements in the models.

For the assessment of human reliability during a fire sequence, the analyst should consider these issues when assigning both the median value of the HEP (which is independent of the uncertainty distribution) and the uncertainty parameters.

8.1.4 Sensitivity Analysis Versus Uncertainty Analysis

Sensitivity methods can be used to evaluate the risk importance of fire related actions instead of assigning uncertainty distributions. While these terms are sometimes used interchangeably, uncertainty analysis refers to applications which propagate the uncertainty of the individual parameter probability distributions through the model to produce an output in the form of a probability distribution based on the distribution of the inputs (e.g., Monte Carlo sampling). Uncertainty analysis can encompass the evaluation of sensitivity cases. Sensitivity analysis includes setting one parameter to a failure value of 1.0 and determining the impact on the result. Most PRA modeling codes provide the capability to perform special types of sensitivity analysis on all the components to produce a risk importance ranking. Two popular methods are Fussell-Vesely and risk achievement worth.

For the determination of human error distributions, the analyst can assign a distribution as discussed below. Either manually setting the value of an HEP to 1.0 or application of the risk importance measures can be used to evaluate the risk importance of the human errors modeled in the fire PRA. If the risk contribution is above a threshold (RG 1.174), then actions need to be considered for reducing the risk impact.

8.2 Fire HRA Applications of Uncertainty

For fire HRA, three approaches were presented for human failure event quantification: screening, scoping and detailed HRA. Methods for characterizing the uncertainty associated with the human error probability are also recommended. For screening, scoping and detailed (EPRI and ATHEANA) HRA methods, the following guidance can be applied.

8.2.1 Screening

In keeping with the simplicity of the screening approach, the assignment of uncertainty is also simplified for screening. The screening HEP values are in the range of 10-3 to 1. Swain NUREG/CR-1278 [3] recommends a range of error factors of 3 to 10, with a lower range in the .001 to .01 range.

In the case of developing uncertainty values for screening HEPs when the clarity of the fire induced scenario is broadly defined, there is not enough evidence to reduce the uncertainty. Therefore, as shown in Table 8-2 for screening HEP values, an EF of 5 applies. The HEP value can be used as a mean value in the PRA model.

Table 8-2
Uncertainty assignment for screening values

Criteria [1]	HEP Value to Apply [2, 4]	Uncertainty Assignment
Set 1 example	0.01	5
Short term example	1	NA [4]
Long Term example	0.001	5
Set 2 example	0.1	5 [4]
Short term example	1	NA [4]
Long term example	0.001	5
Set 3 example	Use both HEPs in sensitivity analysis	NA [4]
Short term example	1	NA [4]
Long term example	0.001	5
Set 4 example	If important to risk use scoping or detailed analysis	NA [4]

Table Notes

1 See Table 8-2 for description of criteria and example cases.

2 For simplicity with PRA assume HEP value is mean of log normal distribution with estimated normal variation error factor of 3 and fire effects of 2 for a total of 5.

3 The HEP screening value should never be lower than the original HEP because fires add complexity to the event.

4 The value of an HEP never exceeds a probability of 1.0.

8.2.2 Scoping

The scoping approach provides much more information about the fire event scenario and the issues that are included and not included. Thus, the uncertainty assigned to the HEP obtained during the scoping process should be lower than that assigned during the screening process. The scoping HEP values are in the range of 10^{-3} to 1. Reference (NUREG/CR-1278) recommends a range of error factors of 3 to 10 over a HEP range of 0.0001 to 0.1. For the detailed analysis of issues outside the scoping analysis, the assigned uncertainty can be larger than the uncertainty related to the scoping analysis, because the detailed analysis addresses issues that are not considered in the screening and scoping analyses, such as self-induced station blackout (SISBO) or similar fault clearance strategies and MCR abandonment.

Uncertainty values for scoping HEPs depend on the clarity of the fire induced scenario definition. Two improvements for reducing uncertainty over the screening process are the ability to precisely answer questions and the separation of specific scenarios for detailed analysis. Therefore, as shown in Table 8-3 for scoping HEP values, when the answers to the questions in the scoping trees are clear, EFs of 1, 3, apply. If the questions are not clearly answered with knowledge of cable routing, the uncertainty estimate for EFs becomes 1, 5 and over the range of HEP values. The scoping HEP values can be considered as median values to be adjusted by the EF to become mean values so they match with the other mean values in the PRA model. If propagation of uncertainty is to be used as a method for tracking overall uncertainty and treating risk important human actions, the scoping HEPs in the trees should be treated as medians. If point estimates are used with sensitivity assessments for overall evaluations of the uncertainty impact there is little error introduced by using the scoping HEPs as either a mean or median.

Table 8-3
Uncertainty categories for scoping analysis

Scoping HEP [1] (median)	Scoping [2] (EF)	Scoping [3] (EF)
Estimated HEP $\geq$ 0.001	3	5
Estimated HEP > 0.1	1	1

Table notes:

1 If propagation of uncertainty modeling is used in the PRA model, the HEP in the scoping tables should be treated as median values, and be adjusted to means based on the uncertainty value.

2 High certainties in answers to scoping questions.

3 Some uncertainty in answers to scoping questions, but bounding by the screening process.

8.2.3 Detailed HRA

Any initial fire scenario model can be modeled in more detail. One method for re-modeling is to separate the drivers of uncertainty into explicit models and then reevaluate the uncertainty in each supporting model. If the uncertainties are considered to be too high leading to HEP values of 1.0 in risk important sequences in the initial PRA model, the NUREG/CR-6850 process focuses on epistemic uncertainties that are represented by unknowns such as cable routing relative to the fire location, and the effects of cable shorting and grounding on controls and instruments associated with fire growth models.

In practice with any detailed approach, areas of uncertainty that are included in the HEP distribution can be separated into specific models to more accurately address a specific issue such as seasonal temperature changes or day night shift dependences using separate models within the PRA logic structure to quantify the impact of the specific condition. For example, if the presence of ice changes a preferred alignment or the way operators react, a special model can include possible deviations due to the ice condition directly on the core damage frequency rather than as part of the uncertainty in the HRA model. The typical aleatory uncertainty such as crew-to-crew variations remain as uncertainty inputs to distributions for both the ice condition HEP and the non ice condition.

By providing this increase in knowledge to the PRA and HRA from other fire modeling tasks the fire effects on the hardware are clearly defined. The uncertainty in the fire scenario and context associated with potential human actions is reduced. In this case the impact of the failure mode variations and variations within scenario become clearly defined for the crews allowing HRA models to better address the specific fire scenario. Actions needed to control the plant from a safety perspective are much better defined in the procedures (e.g., sub-scenarios or extremes represented within a PRA scenario definition), and the rationale for defining unsafe actions is more clearly understood. This increased understanding of the fire context and plant response should permit reduction on the uncertainty in known aspects and increase it in others.

8.2.3.1 EPRI Model

The EPRI approach used to address uncertainty is based on THERP Table 20-20 (also listed in Table 7-2) and guidance in THERP Chapter 7 [3]. THERP's assessment of uncertainty assumes a lognormal distribution. The following is taken directly from THERP Chapter 7:

> "Although we would like to have data clearly showing the distributions of human performance for various NPP tasks, there is ample evidence that the outcomes of HRAs are relatively insensitive to assumptions about such distributions. One example is described in Appendix A8 t o the draft Handbook (Swain and Guttmann, 1980).
>
> Another example is illustrated by an experimental study in which Mills and Hatfield (1974) collected distribution data on task completion times for several realistic tasks. One significant finding was that errors resulting from assuming an incorrect form of the PDF of task times were small and of little practical significance. The distributions, all unimodal, were best described by various Weibull functions, but the authors state, "From a practical point of view, the error produced by assuming normality may not be large enough to warrant using a better - fitting PDF." During the preparation of WASH-1400, a sensitivity analysis was performed by Dr. W. E. Vessely using a Monte Carlo procedure to see if the assumption of different probability density functions for the human error estimates would materially affect the predicted availability of various safety-related subsystems. It was found that the predicted availability did not differ materially when different distributions were assumed.
>
> We can conclude that the assumption of normal, lognormal, or other similar distributions usually will make no material difference in the results of HRA analyses for NPP operations. In some cases, this insensitivity may result from a well-designed system that has so many recovery factors that the effect of any one human error on the system is not substantial. If very different distributions such as a bimodal type, an exponential, or an extreme value were used, it is possible that different results could be obtained. For computational convenience, one might wish to assume the same distribution for probabilities of human failure as the one used for probabilities of equipment failure, as was used in WASH-1400. A sensitivity analysis will reveal whether any significant differences will be obtained with different assumptions."

Since the publication of THERP, the EPRI HCR/ORE [5] studies were performed. The data for time to a corrective action that was collected could be fit to a number of distributions where the mean and the median can differ (in the normal distribution, the mean and median are the same). For mathematical convenience a lognormal distribution was selected to represent the time-based probability of success distribution, although the Weibull distribution provides equally good fits.

The THERP approach to uncertainty is to assign an error factor solely based on the final HEP. Since the approach is not based on the initiators, it can be applied to all initiators including fire. The EPRI approach for fire is to apply the same error factors as for internal events, and the factors are shown in Table 8-4.

Table 8-4
EPRI uncertainty categories for EPRI detailed analysis

HEP	Reference	Error Factor
Estimated HEP < 0.001	THERP Table 20-20	10
Estimated HEP > 0.001	THERP Table 20-20	5
Estimated HEP > 0.1	Mathematical convenience	1

8.2.3.2 ATHEANA

Guidance on addressing uncertainty, and other issues associated with eliciting probabilities is given in the ATHEANA User's Guide (NUREG-1880).

The approach begins with detailed qualitative discussions to ensure all the available information (evidence) is brought to the table, shared, and agreed upon to the extent possible. It is a facilitated process to control bias and ensure all participants participate in a meaningful way. All qualitative and quantitative evidence is presented, justified, and discussed. All participants must contribute their own ideas, evidence, and preliminary estimates. The final distribution is selected to give credence to alternative qualitative and quantitative evidence that the experts believe would reflect a reasonable consensus of the technical community. The mean HEP and other statistics can be calculated from the consensus distribution.

The elicitation process includes a detailed identification of the key factors contributing to aleatory and epistemic uncertainty. Ideally, the process generates probability distributions that include epistemic uncertainty to address lack of knowledge and aleatory to address stochastic variability. Then the distributions can be combined mathematically, accounting for the likelihood of the event occurring under both epistemic (e.g., lack of knowledge about the fire impacts) and aleatory conditions (e.g., circadian rhythms, season variation effects and other factors that are addressed as being independent of the fire). In practice, these assessments of uncertainty are sometimes integrated by consensus of the experts in a single step. The HEP in a fire scenario may be made up of combinations of distributions of multiple unsafe actions that have been evaluated separately. The individual distributions can be combined mathematically into a single distribution, from which a statistical representation can be calculated.

8.3 Additional Guidance for Uncertainty

The in addition to the references discussed in this section the following list of references are applicable to internal HRA and can be referenced for fire HRA if additional guidance is desired.

1. EPRI 1009652, "Guideline for Treatment of Uncertainty in Risk-Informed Applications", December 2005.
2. NRC Inspection Report No. EA-03-016 - Arkansas Nuclear 1 - 50-313/01-06; 368/01-06 Entergy Operations, Inc. Enclosure 2, April 7, 2004.
3. NUREG-1855, "Guidance On Treatment of Uncertainties Associated with PRAs in Risk Informed Decision Making", (DRAFT), November 2007.

8.4 References

1. BSR/ANS 58.23, "FPRA Methodology Standard", December 2006 (Note)
   - Note: These Fire HRA Guidelines were originally written to the December 2006 draft version of the Fire PRA Methodology standard which ultimately became ANSI/ANS-58.23-2007 in November 2007. Some sections also cite ASME PRA-S-2000, "Standard for PRA for Nuclear Power Plant Applications", and its addenda ASME RA-Sa-2003 and ASME RA-Sb-2005, as they relate to internal events PRA issues that apply to Fire PRA/HRA. It was decided to issue this version of the Fire HRA Guidelines for public review and comment rather than delay it further to resolve any inconsistencies between the draft and final versions of the ANS standard, or to review and incorporate information from the recently published ASME/ANS RA-S-2008, "Level 1 and Large Early Release Frequency (LERF) PRA Standard", which applies to at-power internal events, internal fire events, and external events for operating reactors. The necessary reviews and revisions to reflect the latest standards will be addressed prior to issuing the final Fire HRA Guidelines.
2. ASME RA-S-2000, "Standard for PRA for Nuclear Power Plant Applications", Rev 14A, May 11, 2001 supplemented by ASME RA-Sa-2003, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 5, 2003, supplemented by ASME RA-Sb-2005, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 2005, all by American Society of Mechanical Engineers.
3. 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.
4. Regulatory Guide 1.174, "An Approach For Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis", U.S. Nuclear Regulatory Commission, Revision 1 November 2002.
5. *Operator Reliability Experiments Using Nuclear Power Plant Simulators.* Electric Power Research Institute, July 1990. EPRI NP-6937.
6. Software Users Manual, *The Human Reliability Calculator Version 4.0*. EPRI, Palo Alto, CA, and Scientech, Tukwila, WA: January 2008. Product ID. 1015358.
7. NUREG-1880, "ATHEANA User's Guide", Final Report, U.S. NRC, Washington, DC, June 2007.

9 DOCUMENTATION

In accordance with NUREG/CR-6850 [1] the output of this entire task is a calculation package. In connection with the ASME Standard [2], this package should contain:

- all human actions and associated HFEs considered in the fire analysis,
- the description of the HFE and especially its context in the fire scenarios,
- the quantification method (screening or best-estimate), including the method/tools that were used,
- the basis for the derivation of the HEP with particular attention as to the evaluation of (1) dependency considerations and (2) the PSFs and related fire effects, the assigned HEP uncertainty values and their bases,
- an assessment of the assumption’s sensitivity in the HRA modeling and quantification to the PRA risk measures,
- The method and treatment of dependencies for post-initiator actions,
- Table of pre- and post-initiator human actions evaluated by the model, system, initiating event, and function,
- HEPs for recovery actions and their dependences with other actions.

9.1 References

1. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*. September 2005. NUREG/CR-6850/EPRI 1011989.
2. ASME RA-S-2000, “Standard for PRA for Nuclear Power Plant Applications”, Rev 14A, May 11, 2001 supplemented by ASME RA-Sa-2003, “Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications”, December 5, 2003, supplemented by ASME RA-Sb-2005, “Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications”, December 2005, all by American Society of Mechanical Engineers.

A
FIRE PRA STANDARD AND THE FIRE HRA GUIDANCE

A.1 Objective

This appendix discusses the relationship between the fire HRA guidance in this document, used to support the development of a fire PRA following NUREG/CR-6850 guidance [1], and that provided in Fire PRA Methodology Standard [2]. The intent of examining the relationship between these documents is twofold.

- First, to ensure that relevant technical issues are considered in the development of this guidance, e.g., number of spurious instrument operations that may prevent or delay a desirable action (error of omission, EOO) or cause an inappropriate action (error of commission, EOC), and
- Second, to examine how the fire HRA guidance provided herein maps into various capability categories of the standard to ensure that the guidance can meet the capability category desired by the user.

A.2 Fire PRA Standard Requirements Relevant to Fire HRA

A.2.1 Identification of Actions and Definition of HFEs

HRA-A1 and HRA-A2 set the requirements for identification of important human actions carried over from the Internal Events PRA (EOP actions) and those called out in the fire procedures, respectively.

HRA-B1, HRA-B2 and HRA-B3 set the requirements for defining human failure events that are carried over from the Internal Events PRA (EOP actions), those called out in the plant fire response procedures (FRP actions), and undesired operator action (EOC), respectively.

The undesired operator response actions (often called errors of commission, EOC) are typically identified and defined, for the sake of efficiency, starting with the malfunctioning instruments and/or alarms that may trigger such actions. Therefore, identification/definition of EOCs relies on instruments and/or alarms (including the number of instrument and/or alarm spurious operations) selected in supporting requirements ES-C1 and ES-C2.

An important caveat regarding the depth of investigation required for multiple spurious operations is set forth in Discussion 2 under ES-C2, namely: “Consideration of just one fire-induced spurious indication relevant to each operator action being addressed for Capability

Categories I and II is indicative of balancing (a) the current state of the art and the resources required to consider almost innumerable combinations of two or more spurious indications against (b) the desire to capture in the fire PRA the associated risk caused by such spurious indications." Discussion 3 notes that "Capability Category III includes consideration of other instrumentation not needed to directly affect the modeled actions (e.g., other "nuisance" alarms or indications) but that may still cause undesired operator effects that are relevant to the Fire PRA."

A.2.2 Estimating Screening/Scoping/Detailed HEPs

HRA-C1 and HRA-D1 require that all HFEs and recovery actions identified/defined be quantified, unless a basis is provided for not doing so.

The graded application of this requirement is implied per the gradations in the internal events (non-fire) PRA standard [3] high-level requirement HLR-HR-G, as shown in Table A-1, and associated supporting requirements with the caveat that the PSFs of the ASME standard are complemented with the fire-specific PSFs discussed in this report.

Table A-1
Internal events PRA standard requirements HR-G3, HR-G4, and HR-G5 [1]

	Capability Category I	Capability Category II	Capability Category III
HR-G3	**USE an approach that takes the following into account:** (a) the complexity of the response (b) the time available and time required to complete the response **(c) some measure of scenario-induced stress** **The ASEP Approach is an acceptable approach.**	**When estimating HEPs EVALUATE the impact of the following plant-specific and scenario-specific performance shaping factors:** **(a) quality [type (classroom or simulator) and frequency] of the operator training or experience** **(b) quality of the written procedures and administrative controls** **(c) availability of instrumentation needed to take corrective actions** **(d) degree of clarity of cues/indications** **(e) human-machine interface** (f) time available and time required to complete the response (g) complexity of the required response **(h) environment (e.g., lighting, heat, radiation) under which the operator is working** **(i) accessibility of the equipment requiring manipulation** **(j) necessity, adequacy, and availability of special tools, parts, clothing, etc.**	
HR-G4	BASE the time available to complete actions on **applicable generic studies (e.g., thermal/ hydraulic analysis for similar plants)**. SPECIFY the point in time at which operators are expected to receive relevant indications.	BASE the time available to complete actions **on appropriate realistic generic thermal/hydraulic analyses, or simulation from similar plants (e.g., plant of similar design and operation).** SPECIFY the point in time at which operators are expected to receive relevant indications.	BASE the time available to complete actions on **plant-specific thermal/hydraulic analysis, or simulations.** SPECIFY the point in time at which operators are expected to receive relevant indications.
HR-G5	When needed, **ESTIMATE** the time required to complete actions. **The approach described in ASEP is an acceptable approach.**	When needed, **BASE** the required time to complete actions **for significant HFEs on action time measurements in either walkthroughs or talk-throughs of the procedures or simulator observations.**	When needed, **BASE** the required time to complete actions **on action time measurements in either walkthroughs or talk-throughs of the procedures or simulator observations.**

[1] While the performance shaping factors (PSFs) listed in this table have slightly different wording, they cover the same attributes of the fire PSFs listed in NUREG/CR-6850 and this document.

A.3 Review of the EPRI/NRC-RES Fire HRA Guidance against the Relevant Requirements of the Fire PRA Standard

This section describes a comparison of a fire human reliability analyses carried out based on the guidance provided in this document against the requirements set forth in the Fire PRA Methodology Standard pertaining to HRA [2]. It is not the intent of this section to be an assessment of this guidance, rather to offer a roadmap for the users of this guide to perform an assessment of their own analyses against the requirements of the Fire PRA Standard.

A.4 References

1. NUREG/CR-6850/EPRI 1011989, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," September 2005.
2. BSR/ANS 58.23, "FPRA Methodology Standard" December 2006 (Note).

   Note: These Fire HRA Guidelines were originally written to the December 2006 draft version of the Fire PRA Methodology standard which ultimately became ANSI/ANS-58.23-2007 in November 2007. Some sections also cite ASME PRA-S-2000, "Standard for PRA for Nuclear Power Plant Applications", and its addenda ASME RA-Sa-2003 and ASME RA-Sb-2005, as they relate to internal events PRA issues that apply to Fire PRA/HRA. It was decided to issue this version of the Fire HRA Guidelines for public review and comment rather than delay it further to resolve any inconsistencies between the draft and final versions of the ANS standard, or to review and incorporate information from the recently published ASME/ANS RA-S-2008, "Level 1 and Large Early Release Frequency (LERF) PRA Standard", which applies to at-power internal events, internal fire events, and external events for operating reactors. The necessary reviews and revisions to reflect the latest standards will be addressed prior to issuing the final Fire HRA Guidelines.
3. ASME RA-S-2000, "Standard for PRA for Nuclear Power Plant Applications", Rev 14A, May 11, 2001 supplemented by ASME RA-Sa-2003, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 5, 2003, supplemented by ASME RA-Sb-2005, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 2005, all by American Society of Mechanical Engineers.

Table A-2
ANS 58.23-2007 standard requirements vs. HRA steps identified in this document

<table>
<tr><th>Step in this Method</th><th>Index No.</th><th>CC-I</th><th>CC-II</th><th>CC-III</th></tr>
<tr><td rowspan="2">Identification</td><td>HRA-A1</td><td colspan="3">For each fire scenario, for each safe shutdown action carried over from the Internal Events PRA, DETERMINE whether or not each action remains relevant and valid in the context of the Fire PRA consistent with the scope of selected equipment per the ES element and plant response model per the PRM element of this standard, and in accordance with HLR-HR-E and its Supporting Requirements (SRs) in Section 2 with the following clarifications:
• Where SR HR-E1 mentions “in the context of the accident scenarios,” specific attention is to be given to the fact that these are fire scenarios
and
DEVELOP a defined basis to support the claim of nonapplicability of any of the requirements under HLR-HR-E in Section 2.</td></tr>
<tr><td>HRA-A2</td><td colspan="3">For each fire scenario, IDENTIFY any new fire-specific safe shutdown actions called out in the plant fire response procedures (e.g., de-energizing equipment per a fire procedure for a specific fire location) consistent with the scope of selected equipment from the ES and PRM elements of this standard, and in accordance with HLR-HR-E and its SRs in Section 2 with the following clarifications:
• Where SR HR-E1 discusses procedures, this is to be extended to procedures for responding to fires;
• Where SR HR-E1 mentions “in the context of the accident scenarios,” specific attention is to be given to the fact that these are fire scenarios;
• Another source for SR HR-E1 is likely to be the current Fire Safe Shutdown/Appendix R analysis,
and
DEVELOP a defined basis to support the claim of nonapplicability of any of the requirements under HLR-HR-E in Section 2.</td></tr>
<tr><td rowspan="3">Definition</td><td>HRA-B1</td><td colspan="3">INCLUDE and MODIFY, if necessary, human failure events (HFEs) corresponding to the actions identified per SRs HRA-A1 in the Fire PRA plant response model consistent with Secs. 4.6 and 4.9, and in accordance with HLR-HR-F and its SRs in ASME-RA-2002/RA-Sb-2005.</td></tr>
<tr><td>HRA-B2</td><td colspan="3">INCLUDE new fire-related safe shutdown HFEs corresponding to the actions identified per SR HRA-A2 in the Fire PRA plant response model consistent with Secs. 4.6 and 4.9, and in accordance with HLR-HR-F and its SRs in ASME-RA-2002/RA-Sb-2005.</td></tr>
<tr><td>HRA-B3</td><td colspan="3">INCLUDE HFEs for cases where fire-induced instrumentation failures or spurious indication could cause an undesired operator action, consistent with HLR-ES-C of this standard and in accordance with HLR-HR-F and its SRs in ASME-RA-2002/RA-Sb-2005.</td></tr>
<tr><td></td><td>All</td><td colspan="3">DEVELOP a defined basis to support the claim of nonapplicability of any of the requirements under HLR-HR-F in ASME-RA-2002/RA-Sb-2005.</td></tr>
</table>

Table A-2
ANS 58.23-2007 standard requirements vs. HRA steps identified in this document (continued)

Step in this Method	Index No.	CC-I	CC-II	CC-III
Screening Fire HRA Scoping Fire HRA Detailed Fire HRA	HRA-C1	For each selected fire scenario, QUANTIFY the HEPs for all HFEs and ACCOUNT FOR relevant fire-related effects for both screening/conservative values as well as detailed assessments, in accordance with HLR-HR-G and its SRs in ASME-RA-2002/RA-Sb-2005 with the following clarification: • Attention is to be given to how the fire situation alters any previous assessments in nonfire analyses as to the influencing factors and the timing considerations covered in SRs HR-G3, HR-G4, and HR-G5 in ASME-RA-20020RA-Sb-2005, and DEVELOP a defined basis to support the claim of nonapplicability of any of the requirements under HLR-HR-G in ASME-RA-2002/RA-Sb-2005. **[NOTE: SEE TABLE A1 above for HR-G3, -G4 and G5 requirements]** Discussion 1: The graded application of this requirement is implied per the gradations in ASME-RA-2002/RA-Sb-2005 @2# for the SRs under HLR-HR-G. Discussion 2: The Fire PRA context introduces new aspects to those performance shaping factors (PSFs) already identified in the ASME requirements (e.g., the effects of the environmental conditions would need to consider relevant fire environments), or might introduce new PSFs (e.g., the fact that one operator is generally assigned as member of the fire brigade or the added burden associated with post-fire operator actions). The intent of SR HRA-C1 is to ensure treatment of such factors.		
Recovery	HRA-D1	INCLUDE recovery actions and ACCOUNT FOR relevant fire-related effects in accordance with HLR-HR-H and its SRs in ASME-RA-2002/RA-Sb-2005 with the following clarification: • Attention is to be given to how the fire situation alters any previous recovery action assessments in nonfire analyses and DEVELOP a defined basis to support the claim of nonapplicability of any of the requirements under HLR-HR-H in ASME-RA-20020RA-Sb-2005.		
Dependency		Not specifically addressed		
Uncertainty	HLR-UNC-A	The Fire PRA shall identify key sources of CDF and LERF uncertainties, including key assumptions and modeling approximations. These uncertainties shall be characterized such that their impacts on the results are understood. [NOTE: No specific discussion regarding HRA-related uncertainty for HFEs]		
Documentation	HRA-E1	DOCUMENT the Fire PRA HRA including • those fire-related influences that affect the methods, processes, or assumptions used as well as the identification and quantification of the HFEs/HEPs in accordance with HLR HR-I and its SRs in ASME-RA-2002/RA-Sb-2005, and DEVELOP a defined basis to support the claim of nonapplicability of any of the requirements under HLR-HR-I in ASME-RA-2002/RA-Sb-2005, and • any defined bases to support the claim of nonapplicability of any of the referenced requirements in ASME-RA-20020RA-Sb-2005 beyond that already covered by the clarifications in this section.		

B
FIRE EVENT REVIEW

B.1 Objective

This appendix documents a review of the significant fire events in the U.S. and internationally - a source of information in the development of this guide. Specifically, this review was intended to:

- Serve as a check for the fire performance shaping factors defined in this document (also, in NUREG/CR-6850 and NUREG 1852, Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire) and how they may manifest themselves in response of crew to actual events,
- Gain insights into how different crews respond to different actual fire scenarios (variability) and how these lessons may influence development of a fire HRA method, both qualitatively (e.g., as part of the basis for qualitative screening rule-sets or assumptions) and quantitatively (e.g., as part of the basis for the screening values).

B.2 Fire Events Review

Tables B-1 through B-3 provide summaries of the review of three fire events. These summaries are developed, for the most part, based on the information documented following a fire event, e.g., as part of a root-cause analysis. The interpretations do not reflect any changes that may have occurred since then. Such changes may include changes in operator training, possibly as the result of this or other events.

The information on each event is organized in the following way:

- First, the information relevant to each fire performance shaping factor is extracted from the fire event description from the analysis. This is intended to help characterize how operator response to an actual fire can be associated with these PSFs and whether there are additional issues to be covered.
- Second, an assessment/discussion is provided regarding if and how the information could impact various steps of the fire HRA.

B.3 Summary of Fire Events Review Findings and Implications

The following key issues were identified as important for consideration in the fire HRA methods based on an evaluation of the findings and implications from the fire events review. These issues appear to have been addressed through the timing, staffing and indication portions of the EPRI HRA quantification methodology presented in Appendix C, as well as the consideration of fire-specific performance shaping factors in the scoping analysis as outlined in Appendix H, section H.3 and in the detailed analysis as indicated in Appendix C, section C.2.

- Actual fire events can occur in different and unexpected ways due to fire induced spurious equipment operations or inaccurate instrument readings that act as a cue to unsafe operator actions. The unpredictability of the fire adds to stress, workload and issues that need attention by the crew (for example more alarms than expected and/or a potential loss of annunciators). Simulator exercises, based on a pre-defined fire scenario and component failure conditions for the fire zone, model only one possible set of control room conditions. One scenario selected for simulation is not necessarily the most risk significant. Differences between training scenarios and actual events can also add stress to the crew which can be reflected in the uncertainty of a HFE.
- Detailed HRA response modeling needs to look at timing of cues, time windows and manipulation time.
- Smoke in the control room and crew knowledge that the fire was continuing to burn for some time both added to the stress level of the crew and may have contributed to the overall workload/burden of the crew.
- Fire could be made worse (in spite of good intentions) by some operator actions (e.g., restore lube oil to hot bearings) or inactions (delay of water on the fire) because of lack of knowledge or training.
- Incorporation of experience from previous events into procedures and training should be credited in the basic HEPs.
- The HRA process guidance should address both possibilities of leaving the MCR when it is not really necessary, as well as leaving when perhaps it is too late.
- Staffing levels of MCR personnel and those out in the plant performing local actions, as well as the impact of fire fighting staff at a barely adequate level, should be considered in the detailed HRA if a significant number of local manual actions are needed to achieve safe shutdown during a fire.
- HRA model credit can be given for an ex-control room task when the task walk down is performed and demonstrates timing is reasonable, there is space for air packs, and the path is not through the fire zone. Consideration should also be given to number and adequacy of system(s) of communication between the MCR and remote staff, since important communications to achieve safe shutdown during a fire are required for any ex-control room actions. If three diverse communications (including radio or wireless) are available, then no penalty is needed.
- The use of SCBAs can be key in maintaining the plants in a safe shutdown condition. These tools should be available to the plant operators for electrical fires.

Table B-1
Summary of the fire event 1 review

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Applicability and Suitability of Training/Experience	Ineffective training stated as a contributing factor regarding interpretation of EOP by the TSC and the monitoring of all relevant indications by the crew so as to fully understand the plant status (see Operator Action Tendencies and Informal Rules, below). The fact that the simulator could not simulate a cooldown from low power condition contributed to the overall lack of familiarity by the crew as to what to expect. Crew exacerbated the cooldown when they opened the auxiliary SG feed nozzles but failed to close the main feedwater SG nozzles (perhaps a training issue).	In spite of problems, there is nothing that indicates that the fact there was a fire contributed to these problems.
Suitability of Relevant Procedures and Administrative Controls	Procedural guidance was not sufficiently explicit for specifying the start point of the temperature decrease as well as what was meant by being in a plant state with emergency injection; this led to the misunderstanding by the TSC that the ES criteria could only be satisfied with 3 pumps running and that operation in the TSOR region was not necessary (when actually, the ES criteria had been met and operation in the TSOR region was necessary). Lack of procedural guidance regarding the closing of main feedwater SG nozzles when using the auxiliary nozzles to the SGs in order to attain natural circulation. Hence, the crew was doing this based on memory.	In spite of problems, there is nothing that indicates that the fact there was a fire contributed to these problems.

Table B-1
Summary of the fire event 1 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Operator Action Tendencies and Informal Rules	Appears there was a tendency of crew members to focus on some indications to the detriment of monitoring the entire situation (see 1st observation under Team/Crew Dynamics and Crew Characteristics) TSC decided not to perform the required operation in the TSOR region once the reactor overcooling had occurred. This is stated as being due to improper interpretation of the EOP guidance for when such operation is required. Lack of more explicit guidance in the procedure, and apparently, a proper focus in training contributed to the misinterpretation. Some personnel in the TSC also were under the erroneous assumption that “HPI in the ES mode” meant that all three HPI pumps were on and injecting through both headers.	In spite of problems, there is nothing that indicates that the fact there was a fire contributed to these problems.
Availability and Clarity of Instrumentation (Cues to Take Actions and Confirm Expected Plant Response)	Nothing to indicate that there were failed or inadequate instrumentation.	No implications based on this event.
Time Available and Time Required to Complete the Act, Including the Impact of Concurrent and Competing Activities	Nothing to indicate that the crew was rushed or otherwise sensitive to a time constraint.	No implications based on this event.
Complexity of the Required Diagnosis and Response, the Need for Special Sequencing, and the Familiarity of the Situation	Crew was not familiar with expectations regarding a possible cooldown when at a low power condition due to the simulator not being capable of simulating such an event (this is in spite of classroom discussions that did cover the relevant issues).	No implications based on this event.

Table B-1
Summary of the fire event 1 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Workload, Time Pressure, and Stress	Operator burden was high (as stated in the documentation of the event) due to numerous factors including smoke in the control room, higher stress knowing that the fire fighting activities were not being successful, and dealing with numerous equipment failures both independent of the fire as well as due to fire-induced failure of the ICS because of erroneous signals.	Smoke in the control room and crew knowledge that the fire was continuing to burn for some time both added to the stress level of the crew and may have contributed to the overall workload/burden of the crew. The fact that some added stress/burden can occur as a result of a fire situation needs to be accounted for in a Fire HRA method. In this event, the crew made some errors in dealing with the event although to what extent the fire vs. other independent failures contributed to the operator failures is not known.
Team/Crew Dynamics and Crew Characteristics [Degree of Independence Among Individuals, Operator Attitudes/Biases/Rules, Use of Status Checks, Approach for Implementing Procedures (e.g., Aggressive Crew vs. Slow/Methodical Crew)]	Entire crew became focused on RCS pressure rise and incore thermocouples to ensure adequate core cooling, but did not also monitor cold leg temperatures and technical specification cooldown rates as they are supposed to do. Therefore they were not aware that the vessel was being subjected to an overcooling transient. Reasons given for these errors stated as ineffective training and operator burden. Management deficiency, deficient supervision also contributed from the standpoint of not requiring operation in the TSOR region (which should have been done) and inappropriately having the operations coordinator direct the staff to use auxiliary spray in violation of a technical specification limit (which apparently was discussed but not appropriately followed through when the coordinator did not realize that pressurizer temperature was elevated).	Operator burden acknowledged as a contributing factor to errors that were made. See above observation under Workload, Time Pressure, and Stress.

Table B-1
Summary of the fire event 1 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Available Staffing/Resources	No indication with regard to staffing issues relative to safe shutdown though fire-fighting staffing was deemed barely adequate.	No direct implications due to this event but the staffing issue is something that should be considered if a significant number of local manual actions are needed to achieve safe shutdown during a fire.
Ergonomic Quality of the Human-System Interface (HSI)	Nothing indicates this was a problem.	No implications based on this event.
Environment in Which the Action Needs To Be Performed	There was smoke in the control room.	Environment considerations, especially smoke and heat need to be accounted for in a fire HRA method.
Accessibility and Operability of the Equipment To Be Manipulated	Nothing indicates this was a problem.	No implications based on this event.
Need for Special Tools (Keys, Ladders, Hoses, Clothing Such as To Enter a Radiation Area)	Nothing indicates this was a problem.	No implications based on this event.
Communications (Strategy and Coordination) and Whether One Can Be Easily Heard	Nothing indicates this was a problem relative to safe shutdown although local communications among the fire brigade were difficult due to high noise level from ejector relief valves lifting and the fact that hands-free communication was not available while in SCBAs.	No direct implications due to this event but the communications issue does suggest something that should be considered if a significant amount of communication is needed to achieve safe shutdown during a fire (including effects in a very noisy environment).
Special Fitness Needs	Nothing indicates this was a problem.	No implications based on this event.

Table B-2
Summary of the fire event 2 review

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Applicability and Suitability of Training/Experience	Training addresses key fire issues at this plant, e.g. in Attachment 1 of their Abnormal Operating Instructions (AOI), which provides warnings about equipment that could be affected and lessons learned. Operators perform a bi-annual walk through of shutdown tasks outside the MCR in the plant. They walk to every action and time those that have time requirements in the AOI. Generally the operators don't do simulator drills on the fire AOI and controlling the plant from outside the MCR. . The simulator training cycle is every 4 years for the fire AOI because fire specifics are not thought to be difficult; other AOIs train on a 2 year cycle. The philosophy of training is to focus on effect rather than cause. Operators receive 200 hours/year of training. They are trained to respond to a safety system with functional response procedures. Trainers are not sure if being in a fire would cause operators to mistrust instruments/alarms. The focus is on using multiple indications for decision-making. The safety of the fire fighters was a primary concern in reluctance to use water, along with a secondary concern about what else might fail. It was finally decided that water would be used on the fire. Later learned that all the hose nozzles on site are 10,000 volt capable nozzles. [Unknown technical feature related to training.] Training changes were implemented as a result of the fire. Operators need additional fire training, especially for first responders and in managing fires. The training needs to address issues outside the procedures and ability to adapt to the needs of the situation.	The event demonstrates that for training, procedure guidance, and simulator exercises, similar but "real fire events" can occur in unexpected ways adding to the workload and issues that need attention by the crew (e.g., more alarms than expected, or loss of annunciators). The HRA process should allow for the lack of "detailed" knowledge that could lead to further exacerbation of the event by the crew. Just as often there is insufficient appreciation for or knowledge about the subtleties of control and interlock circuits, therefore, the fire could be made worse by some operator actions (e.g., restore lube oil to hot bearings) or inactions (delay of water on the fire) because of lack of knowledge or training.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Suitability of Relevant Procedures and Administrative Controls	During a fire the AOI is assigned to a licensed crew member who is the primary communicator with the fire brigade. The remaining crew continues using the EOPs, which is typical of all AOI's. The operating crew was in the fire AOI and the reactor trip procedure at the same time. There were so many AOIs going on that coordination and setting priorities was somewhat difficult. The plant fire procedure AOI should include consideration of potential complications in fire events.	When attempting to estimate operator performance and assign both screening human error probabilities (HEPs) and detailed HEPs, the HRA process should address the need to consider how the crew might logically but still incorrectly worsen the situation in spite of good intentions. The HRA procedure should allow credit for proper operator response especially if sufficient time exists and the plant status is accommodating so that the crew can "compartmentalize" its thoughts and actions, and prioritize them in a way to ensure the operators' response is in accordance with the severity of the threats imposed by the event.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Operator Action Tendencies and Informal Rules	Shutting the MSIVs was common practice for a trip and is now in the procedures. Details for restoring annunciators have been added to the alarm response procedures that are similar to what the operators actually did during the fire. Control Room Supervisor (CRS) - Within about 5-10 minutes, the MCR crew had indications that the main turbine bearing temperatures were over 700o F. Initially they were going to attempt to get lube oil back but an available engineer said that the flash point of lube oil is 400 degrees, so it was decided that they would not proceed to recover lube oil. It was also realized that they had 800 lb. of hydrogen stored above the turbine, so they vented it to 10 lb. In consideration of MCR evacuation some rules of thumb are Fires make a lot of smoke and you hear about people dying from smoke inhalation. Therefore, therefore some operators have a low smoke threshold for MCR habitability. The Shift Manager has the ultimate say in MCR evacuation. In response to this fire, for safety, MCR operators must now ensure that a breaker room is clear of personnel before switching 4 KV power supplies. Before the breaker explosion and fire, switching operations were not recognized as hazardous. By comparison, the long term practice is not to stand next to a pump that is being started.	Plant training needs to continue using operating experience to understand informal rules and incorporate them into procedures. The detailed HRA process should allow credit for informal rules after they have been incorporated into procedures, perhaps as notes. They should also consider the potential for application of training knowledge.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Availability and Clarity of Instrumentation (Cues to Take Actions and Confirm Expected Plant Response)	Following the reactor trip, it was immediately clear that severe electrical power problems existed in the non-nuclear secondary side of the plant. As a by-product of this, it was very quiet in the MCR, with no alarms to silence. It was clear to the RO (crew), very quickly, that the secondary side of the plant was largely affected. Within minutes of the trip, the loss of annunciators had taken out all switchyard indications. However, the SRO was comfortable with the primary system status instrumentation and had the STA doing 15 minute safety function checks. Additional complexities developed as a result of draining water from secondary system pump seals and the resulting flooding. With both the primary system and steam generator feed status OK, he focused on getting annunciator alarms back, going upstairs from the main control room (MCR) to get the annunciator panels back in the same room with the supply source. He tried to re-power the bus, but it tripped again. Next he stripped the bus and successfully re-powered it. At around the time he started to restore loads, the MCR learned about the fire. Someone who had just left the switchgear room and saw the fire start, reported it. So he decided to just energize the most important loads until the fire could be investigated. There was uncertainty in how the control room was notified of the fire. Most likely notification was a manual report from the field, because the fire alarm is often unreliable due to steam detections or bypassing the fire computer frequently for maintenance.	The crew can overcome some amount of loss of indications and or alarms or even confusing indications, and so the HRA process should not penalize expected operator performance too severely for minor indication losses or discrepancies during a fire. However, to what extent such failures can be accommodated before they do hamper operator performance is not clear from this event. The HRA process includes the use of screening sets. This event supports an increase in the screening HEP value. This fire was not as challenging from a safe shutdown perspective as was first thought. The safe condition of the primary system and the steam generator feed was never in jeopardy although there were other issues that had to be dealt with. Therefore, it should be recognized for purposes of the detailed HRA process, that what we can learn from this fire event is not necessarily relevant to a severe safety function challenge situation.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Time Available and Time Required to Complete the Act, Including the Impact of Concurrent and Competing Activities	This was a unique situation, usually there are numerous alarms coming in after a trip which can be much more distracting than the fire. In his nuclear safety area, conditions (pressure, temperature…) were stable and charging was started within the first 2 minutes. The crew thought that there could have been someone in the breaker room at the time of the fire. This would have accounted for the crew knowing what was going on so quickly (e.g., the crew knew about the fire within 2-3 minutes of the start of the event). They did about 3 briefs in the first hour. There were so many alarms going on that coordination and setting priorities was somewhat difficult. The shift manager needed these briefs to pull all the information together. The first brief occurred when the MCR crew transitioned out of the trip response EOP. He asked for a brief from the Unit 2 CRS. The STA, SE and Unit 2 CRS worked closely on addressing alarms and the STA kept the SM well informed. It was fortunate that so many people were available. Without them there would have been delays in managing the fire. It was not too significant for the nuclear safety aspects of this particular event. Once the Control Room Supervisor (CRS) knew about the fire in the switchgear room, he was concerned about spurious actuations. Power level in the reactor was very low. CRS was 80% sure that AFW was manually started. The MSIVs were manually closed very soon, since circulating water was unavailable.	Operators were not able to recover the turbine lubrication systems by the time the condition was discovered. All safety systems operated as expected. For detailed HRA modeling, the impact of the fire is to use up more of the time available and crew staffing resources than a similar event without the fire.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Complexity of the Required Diagnosis and Response, the Need for Special Sequencing, and the Familiarity of the Situation	During a normal plant startup the task was shifting from RAT to Unit 3 generator (UAT) at about 30% power, when the first signs of the problems to come were a variety of alarms and loss of all non-1E 4 KV power. The cubicles contained only non-1E power (e.g., like losing the switchyard) that could cause loss of feedwater. The RO reported to the CRS that there was no secondary power and after the reactor trip they ought to trip MSIVs and go onto atmospheric dump. As soon as the UAT breaker closed unexpected alarms appeared in the MCR - first a few and then many more. The compressors are sensitive to grid fluctuations and generate alarms and that happened. The RO used 4 main circ pumps instruments as a check on off-site power and noted that non-safety electrical power was unavailable. 1E power was available. Additionally, there was zero (0) speed indication on the RCPs, but indication lights indicated that they were running; thus the RO was aware of confusion on some plant indications. The RO closed the MSIVs almost immediately because it was obvious they were quickly losing the secondary side of the plant. After learning of the fire, the CRS gave the fire AOI to a RO and the other unit CRS immediately. The fire AOI is not very easy to use, because they do not train on it as often. It also seems to be written for the best case fire, i.e., a fire with no other significant challenges. If something else occurs (e.g., a primary or secondary leak), dealing with the situation could be more of a challenge.	Difference in the simulator and event in the case of a fire apparently increased the stress on the operators. The HRA process should support use of an HEP value increase in screening sets.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Workload, Time Pressure, and Stress	The site had never gone through a real loss of offsite power (LOOP). This event produced many more alarms than in the simulator. The procedures didn't work so well for this LOOP like event, since we had never had one. For example, with no seal water, all secondary pumps leaked enough water to cause flooding. Later, the CST overflowed by gravity drain. During the fire, the staff in the MCR was calm; especially since the primary system and steam generator feed status were OK. From a safe shutdown point of view, everything went fine. As it was learned that they had also lost the main turbine lube oil pumps and there had likely been turbine damage (i.e., a very depressing situation for the staff), the operator's main action tasks dealt with venting hydrogen from the main generator and possibly restoring the lube oil. They did not restore lube oil, however, because the turbine engineer warned that the bearings were too hot and if they restored the lube oil, it might likely start another fire.	Crews remain calm and stick to the tasks even though many things are going wrong. The HRA process should use the increase in stress due to bad news to support an increase in screening HEP values.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Team/Crew Dynamics and Crew Characteristics [Degree of Independence Among Individuals, Operator Attitudes/Biases/Rules, Use of Status Checks, Approach for Implementing Procedures (e.g., Aggressive Crew vs. Slow/Methodical Crew)]	After the fire was announced, an RO went through the turbine hall and approached the switchgear room. He observed that the switchgear room door was open, dense black smoke inside, and felt a strong vibration (from turbine slowing down). He met the Fire Department staff just outside the area. He checked the room ventilation status and found out the fans were powered by the same area so they probably would not be available. The CRS could have declared a fire or an annunciator event; he declared the fire because that's where the most help was needed. He knew that the primary system and steam generator feed status were OK so the focus needed to be on the fire. Standard procedures do not rely on annunciators/alarms at all; rather the instruments are used. Communications in the MCR are handled by CRS. Even in the case of instrument problems, MCR operators are continually trained to rely on multiple indications for decision making, whether there is a fire or not. Trainers have always given operators multiple failures (the operators used to complain about the unreality of these unconnected failures). After the fire the operators became much more tolerant about training with apparently unconnected failures, recognizing what had happened during a real fire.	The site had never gone through a real loss of offsite power (LOOP). “We got many more alarms than we get in the simulator. The procedures didn't work so well for LOOP, since we had never had one. For example with no seal water, all secondary pumps leaked lots of water and caused flooding. Later, the CST overflowed by gravity drain.” The HRA process should support a screening HEP value increase through the use of the screening sets. Detailed HRA response modeling needs to look at timing of cues, time windows and manipulation time.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Available Staffing/Resources	Only 3 operators are needed to carry out the reactor trip EOP, so one RO was an extra man for the AOI procedure. The reactor was shutdown and they soon had secondary cooling via AFW. They soon lost all annunciators (the small alarm tiles) but not the instruments. Some indicator lights went off, some went green. The crew wanted to restore the annunciators. All breakers at the plant use DC control power and the bus they lost killed some control power. The RCPs were still running; they have three power sources (UAT, RAT, and the other unit's RAT). The primary responsibility of the Operations Fire Technical Advisor (OFTA) is advising the fire department on what equipment and materials are important in the room where the fire is located from an operational/safety point of view. The OFTA needs an integrated plant understanding. There is no formal qualification for OFTA; qualification comes with Control Operator qualifications. The OFTA and Fire Department captains and personnel met for the first time during the event. The position is more an "Emergency Tech Advisor" who deals with other emergencies, as well as fire. An RO was assigned to support fire crew during this event.	Being in multiple AOIs and the EOPs at the same time was not too difficult for the operators because of the availability of other staff at the time of the event. This suggests that the crew can handle such multi-tasking even in a fire, if sufficient resources exist and the plant is not severely challenging safety functions. Hence the HRA fire process guidance should not necessarily penalize operator performance too severely for having to be in multiple procedures concurrently in fire situations. The HRA process should permit screening value adjustments even though the impact is expected to be small. However, this event provides little insight as to what extent the operators' response would have been considerably slowed down or otherwise hampered had there been fewer people available or the safety of the plant had also been jeopardized by breaching a fire zone barrier. There is uncertainty in this area.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Ergonomic Quality of the Human-System Interface (HSI)	Manual notification of fire. A few minutes into the event, a guy came running in and said there is a fire, probably a chem. tech. With that announcement, the Shift Manager (SM) started to think about the EPIPs. [Note: SM takes on the EPIPs (emergency coordination and offsite notifications) but does not take over plant procedures.] A couple of minutes after the Trip, they lost annunciators and all noise. Therefore, the MCR crew did not trust indications; so all indications were double checked. The primary system status remained OK during the entire event, with all safety-related buses and equipment always available. During the event the Fire Department asked RO to inspect the room. He was nervous because he had no breathing protection. The SCBAs were not at the location and the Fire Department uses Scott air packs. They don't train the operators on their equipment. The smoke had decreased, so he entered the room and then reported on his observations.	The HRA process should allow for reduced HEPs for actions in smoke filled fire zones if the plant uses methods to train on dealing with smoke and fire situations. Screening values assume no actual fire and smoke training.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Environment in Which the Action Needs To Be Performed	It was too dark in the locker area to find a flashlight. When he got to the room it was dark – only emergency battery-powered lights were on: they were OK but not good lighting. Once his eyes adjusted to the light, he could read the labels. While the lighting loss affected his response a little, he said that overall it was not a major deterrent. With regard to the RO's willingness to abandon the MCR, he indicated he is very willing to leave. He thought that if there was enough smoke to need an air pack, he would prefer to leave instead. This RO's view was that SCBA gear is really provided for earthquake with chemical release. With regard to MCR habitability in other circumstances, the SRO indicated his preferences would be to evacuate if there are flames. If there is just smoke, they would don SCBAs, keep a few persons in the MCR, and simultaneously start manning remote shutdown. If there is only control problems, man both areas (MCR and remote) but the tendency would be to not leave the MCR. With regard to the specific issue of MCR abandonment, it seems clear that the threshold for when it is necessary to do so differs from person to person and is not a clearly defined decision.	At one point, the Fire Department said there were no flames and that the fire on the other side was extinguished. This led to the RO's report to the MCR staff that the fire was 'out'. There was some confusion about this later and now new language has been formalized and only the Fire Department can say that the fire is out. Water was not put on the fire until after he was in the debrief process. Assumption for screening is that no actions are allowed in the fire impacted zone. This can be re-examined in detailed analysis. The HRA process guidance should address both possibilities of leaving the MCR hen it is not really necessary as well as leaving when perhaps it is too late. Further, it seems the HRA process will need to handle cases where persons may be used in both the MCR and in remote locations to deal with the fire event, especially when only overall control is being threatened but the MCR environment is otherwise okay.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Accessibility and Operability of the Equipment To Be Manipulated	They don't actually use keys to get to/through radiation areas. Keys are under Security controls so operations does not test them. If there were to be a problem with the keys, they can get another set of keys. SCBA gear is provided for earthquake with chemical release, and can be used for fire. An OFTA kit was prepared for the future that includes an audio recorder, communications gear, note pads and other materials. This is now available. However, it includes a copy of the fire AOI, which in the operator's judgment may not be particularly useful for the OFTA. The Fire Department carries the fire preplans, which have much more useful on-scene information.	The need for special tools did not impact the safe operation of the shutdown systems. Understanding the capability of the fire nozzle would support more effective use of the existing tools. Additional tools can benefit operators dealing with the situation. Some uncertainty exists regarding the use of procedures with tools in terms of who is in charge. The impact of not knowing the scope of tools is addressed under the screening values in the area of training.
Need for Special Tools (Keys, Ladders, Hoses, Clothing Such as To Enter a Radiation Area)	Control room operators don't actually use keys to get to/through radiation areas. Keys are under Security controls so operations does not test them. If there were to be a problem with the keys, they can get another set of keys. An OFTA kit was prepared for future that includes an audio recorder, communications gear, note pads and other materials. This is now available.	The HRA modeling should evaluate the need for and use of tools on a scenario basis for detailed analysis. The need for special tools did not impact the safe operation of the shutdown systems. Understanding the capability of the fire nozzle would support more effective use of the existing tools. Additional tools can benefit operators dealing with the situation. Some uncertainty exists regarding the use of procedures with tools in terms of who is in charge.

Table B-2
Summary of the fire event 2 review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Communications (Strategy and Coordination) and Whether One Can Be Easily Heard	Operators do periodic briefs during an event: what's happened, current status, and what we're going to do next. They don't routinely describe how they expect the plant to respond. A few minutes into the event, a guy came running in and said there is a fire - probably a chem. tech. CRS could have declared a fire or an annunciator event. He declared a fire because that's where help was needed With regard to how often to talk to the MCR staff, CRS said that that is a judgment call as to how important it is that the MCR staff be made aware of conditions at the scene of the fire.	Thinking of the shift supervisor: Fire was reported out about 15 minutes into the event. A little later, firemen were asking if it was OK to use water. This was confusing since the fire was reported 'out.' Why need to spray the SWGR with water? Firemen want to use water to cool it. Why use water, just let it cool down. The Captain indicated the fire was not yet really out. Four KV is de-energized, but cannot guarantee that lower voltage is de-energized, thus there was concern that firefighters could be at risk. Uncertainty in transmitting knowledge of the situation is addressed in the screening sets. The detailed process should address the need to search for or otherwise consider how the crew might logically but still incorrectly worsen the situation in spite of good intentions.
Special Fitness Needs	All crew passed normal health screening for license.	Some crew members may be impacted by low levels of smoke.

Table B-3
Summary of the fire event 3 (1975) review[8]

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Applicability and Suitability of Training/Experience	The cable spreading room event was new in concept for the team. Little experience on the effects relative to use of EOPs and application of fire fighting techniques. No simulator training available at the time of the event. Lack of knowledge on effects of water on cables needed to put the fire out. The basic training on plant systems provided operations with knowledge and ability to use systems such as the control rod drive cooling system to support injection to the core and maintain core cooling. Did not evaluate precursor fires started by using open flame to test room seal effectiveness.	Lack of training contributed to length of fire progression, loss of multiple systems, and need for creative actions by the plant crew. Detailed HRA should identify areas where advanced operator actions could be developed for procedures/ training. The HEP is set to 1.0 for such actions. Incorporation of experience from previous events into procedures, and training should be credited in the basic HEPs.
Suitability of Relevant Procedures and Administrative Controls	Process for testing seal with an open flame was informal and not in procedures. Procedural guidance was not sufficiently explicit for dealing with fire fighting methods, dealing with confusing instruments, anticipating impact of fire on plant safety systems, and spurious actions caused hot shorts as cable insulation failed. The structure for organizing technical support was absent. Lack of procedural guidance on using systems such as the CRD cooling system. Hence, the crew was taking actions based on system knowledge and problem solving.	Initiating event frequency should cover a range of human activities in the fire zone. The HRA should use conservative bounds for any decision or action that is not in procedures or well known to the operators. Consider HRA credit for formal team planning based on procedures prior to repair tasks (e.g., SAMGs). HEP values close to 1.0 apply to innovative problem solving during the event.

Table B-3
Summary of the fire event 3 (1975) review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Operator Action Tendencies and Informal Rules	The operators did not manually trip the units during the first 30 minutes of the fire. The MCR crews were under the erroneous assumption that use of water on cable fires was a hazard to fire fighters. Use of special fire equipment for this application was unknown to the control room operators. This led to reluctance to declare a fire and apply water to put fire out as a management decision. The operators were not prepared for dealing with confusing instruments and spurious actions caused by the fire. The tendency was to believe instruments until proven illogical. Operators stayed in control room using air pack and temporary air hose set up to clear atmosphere.	The decision to trip should be carefully considered in the HRA for each fire zone. Trip can be assumed to evaluate the challenge to core protection systems. The lack of fire fighting knowledge for the control room allowed the fire to continue for about seven hours after it was initiated. This added stress/burden which needs to be addressed in a fire HRA method. The MCR evacuation decision should consider the MCR environment, the reliability of the instruments and controls, and the training, practice and confidence in using the local control stations or reserve shutdown room.

Table B-3
Summary of the fire event 3 (1975) review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Availability and Clarity of Instrumentation (Cues to Take Actions and Confirm Expected Plant Response)	"Control board indicating lights were randomly glowing brightly, dimming, and going out; numerous alarms occurring; and smoke coming from beneath panel 9-3, which is the control panel for the emergency core cooling system (ECCS). The operator shut down equipment that he determined was not needed, only to have them restart again." Misleading indications that some safety systems were operating; later found not operable. Later review indicates this could be due to hot shorts. The fire caused multiple confusing instrument readings; at least two spurious actions occurred leading to a confusing idea of plant system configuration. Operators reported that an additional control room fire might have occurred due to electrical overload triggered by the degraded cables in the CSR. Operators put it out with a CO2 hand held extinguisher. Some key sensors became unavailable (e.g., suppression pool temperature).	Since operators were not prepared for confusing readings the HRA method should account for this condition. Credit can be given for checking for signal reliability. The HRA method needs to address the impact of operators losing knowledge about the system configuration when mixed control and power cables are in the same tray (zone). The HRA and PRA dependency analysis should consider the added burden of electrically induced secondary fires due to overloaded buses in response to partial grounds and shorts.

Table B-3
Summary of the fire event 3 (1975) review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Time Available and Time Required to Complete the Act, Including the Impact of Concurrent and Competing Activities	The fire was manually detected when it occurred and was reported to control room about 15 minutes later. The fire continued after this period adding to concurrent activities. The crew was rushed to find sources of water to keep the core covered while pumps that were initially tripped as a result of the fire were recovered.	Lack of fire fighting knowledge for the control room staff increases the assigned HEP. Delay in tripping the reactor may reduce the number of safety systems available for injection and decay heat removal. Detailed analysis required to reduce HEP below 1.0, if equipment not addressed in the procedures is to be used. Automated fire detection should give additional time to the system time window.
Complexity of the Required Diagnosis and Response, the Need for Special Sequencing, and the Familiarity of the Situation	Crew was not familiar with plant behavior under the fire event conditions. This event was complicated by misleading indications, some spurious actions and continued fire progression for over five hours impacting both operating units. Although control circuits for many of the systems which could be used for Unit 1 were ultimately disabled by the fire, the station operating personnel were able to institute alternative measures by which the primary system could be depressurized and adequate cooling water supplied to the reactor vessel. Unit 1 was shut down manually and cooled using remote manual relief valve operation and condensate booster pump, and control rod drive system pumps. Unit 2 was shut down and cooled for the first hour by the RCIC. After depressurization, Unit 2 was placed in the RHR shutdown cooling mode with makeup water available from the condensate booster pump and control rod drive system pump.	The HRA needs to evaluate the ability of operating crew to handle fires like the 1975 Brown's Ferry by determining the training, procedures and protections provided by Appendix R modifications. Without proof of procedures, training and instrument protections by fire location to deal with a fire scenario, apply a conservative HEP value of between 0.1 and 1.0 to specific actions. HRA methods do not credit innovative actions until they are understood, trained on and proceduralized.

Table B-3
Summary of the fire event 3 (1975) review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Workload, Time Pressure, and Stress	Operator burden was high due to numerous factors including means for removing smoke from the control room, higher stress knowing that the fire fighting activities were not being successful, and dealing with numerous equipment failures both independent of the fire as well as due to fire-induced failure of the ICS because of erroneous signals.	Smoke in the control room and crew knowledge that the fire was continuing to burn for some time both added to the stress level of the crew and may have contributed to the overall workload/burden of the crew. The fact that some added stress/burden can occur as a result of a fire situation needs to be accounted for in a fire HRA method. In this event, the crew made some errors in dealing with the event although to what extent the fire vs. other independent failures contributed to the operator failures is not known.
Team/Crew Dynamics and Crew Characteristics [Degree of Independence Among Individuals, Operator Attitudes/Biases/Rules, Use of Status Checks, Approach for Implementing Procedures (e.g., Aggressive Crew vs. Slow/Methodical Crew)]	Operators required several attempts to manually operate key valves to align the condensate booster pump on unit 2 because the time required for the manual action exceeded the supply of air in the SCBAs which required recharging. Use of the CARDOX system in the cable spreading room increased the pressure, driving smoke into the control room. Effectiveness of CO_2 was limited in stopping the fire.	Operator burden acknowledged as a contributing factor to errors that were made. See above observation under Workload, Time Pressure, and Stress. HRA method needs to consider additional stress associated with a fire that causes a loss of significant equipment and is difficult to extinguish because it is driven by electrical shorting and grounding.

Table B-3
Summary of the fire event 3 (1975) review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Available Staffing/Resources	People were available because of 2 units, and construction staff. No indication that lack of staff had an impact on safe shutdown though fire-fighting staffing was slow.	The staffing issue needs to be considered on a fire scenario basis. The HRA should not credit manual external actions for safe shutdown unless sufficient staff are normally present.
Ergonomic Quality of the Human-System Interface (HSI)	Lack of an automated fire indication panel by fire zone delayed indication of the fire to the control room – these are standard features in control rooms today.	Use of procedures assumes accurate location of the fire zone for the HRA.
Environment in Which the Action Needs To Be Performed	There was smoke in the control room from both secondary electrical fire and pressurization of the cable spreading room with CO_2. Smoke in the area of key valves hampered operation to maintain safe shutdown.	Environment considerations, especially smoke and heat need to be accounted for in a fire HRA method.
Accessibility and Operability of the Equipment To Be Manipulated	The location of some manual valve operating stations was remote and difficult to reach with SCBAs. Because of the difficulties and lack of practice, the operators accomplished the task in a longer time than it would take under non-fire conditions.	HRA model credit can be given for an ex control room task when the task walk down is performed and demonstrates timing is reasonable, there is space for air packs, and the path is not through the fire zone.
Need for Special Tools (Keys, Ladders, Hoses, Clothing Such as To Enter a Radiation Area)	SCBAs were needed and the ability to recharge was needed. Additional SCBAs would have been useful.	The use of SCBAs was key in maintaining the plants in a safe shutdown condition. These tools should be available to the plant operators for electrical fires.

Table B-3
Summary of the fire event 3 (1975) review (continued)

PSFs	Findings Pertinent to Event	Implications for Fire HRA Method
Communications (Strategy and Coordination) and Whether One Can Be Easily Heard	The overall strategy in both units for safe shutdown was the same, but used different equipment and actions. Following trip use high pressure systems if available, then depressurize manually to the suppression pool, and inject with low pressure systems. Heat removal accomplished through turbine driven systems to avoid the need for electrical driven pumps. Communications were hampered by problems with the phone lines because of complications with the construction phone lines. In plant communications via phone lines were lost.	Since important communications to achieve safe shutdown during a fire are required for any ex control room actions, the HRA method should require more time for actions where only one system of communication between the MCR and LCS is available. If three diverse communications (including radio or wireless) are available then no penalty is needed.
Special Fitness Needs	This event required operations in smoke filled areas and work with heavy SCBAs.	Operators are assumed to pass the required physical required for the license.

C DETAILED QUANTIFICATION OF POST-FIRE HUMAN FAILURE EVENTS USING EPRI FIRE HRA METHODS

C.1 Objective

This purpose of this attachment is to present a detailed methodology for quantification of fire HEPs using the EPRI HRA methods as implemented in the EPRI HRA Calculator [1]. This attachment is structured to follow the EPRI HRA Calculator® [1] using the HCR/ORE and CBDTM [2]/THERP [3] methods for quantification. If the analyst is not using the EPRI HRA Calculator software, then sufficient guidance is provided so that an analyst could quantify the HEP by hand. The EPRI HRA methodologies are 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 human failure events (HFEs).

The EPRI HRA methodology embodies several of the HRA quantification methods currently used in the US industry. It use allows the user to select among the following quantification methods: THERP, ASEP, HCR/ORE, CBDTM, SPAR-H for post-initiator (latent) quantification. These methods are primarily applied to level 1 internal events and LERF HRA. The methods are mostly task-based and decompose operator errors into two categories; cognitive (detection, diagnosis, and decision-making), failure and execution (manipulation or implementation) failure. These HRA methods provide sufficient resolution to meet the needs of the internal events PRA model. The advantage of using existing methods for fire HRA is that they evaluate fundamental aspects and factors affecting human performance, and thus 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.

C.2 EPRI Performance Shaping Factors

NUREG/CR-6850 [5] suggests that the following 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/experiences
- Suitability of relevant procedures

[1] HRA Calculator is s registered trademark of EPRI.

- Availability and clarity of instrumentation
- Time available
- Environment in which act needs to be performed
- Accessibility and operability of equipment to be manipulated
- Need for special tools
- Communications
- Team/crew dynamics
- Special fitness needs

The ASME PRA Standard [7] requires that the PSFs listed in Table C-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 ASME 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 PRA Standard.

Table C-1
ASME PRA standard performance shaping factors

SR	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, radiation) under which the operator is working
	Accessibility of the equipment requiring manipulation
	Necessity, adequacy, and availability of special tools, parts, clothing, etc.
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, increased stress, etc.
	Availability of resources (e.g., personnel)

The general PSFs incorporated in the EPRI HRA methodology are shown in Table C-2. The EPRI HRA methodology was specifically designed to meet the requirements of the ASME PRA Standard and therefore the PSFs in the EPRI HRA methodology reflect those of the ASME PRA Standard.

Table C-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 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, 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 that are considered in the CBDTM implemented in the EPRI HRA methodology are listed in Table C-3.

Table C-3
CBDTM[5] 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 Alternate in Procedure Training on Indication
	p_c b:	Data not attended to	Low vs. High Workload Check vs. Monitor Front vs. Back Panel Alarmed vs. 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 vs. 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” & “OR” 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 [8], the ASME PRA Standard and the CBDTM/THERP as embodied in the EPRI HRA methodology are summarized in Table C-4.

Table C-4
Performance shaping factors mapping

NUREG-1792	ASME PRA Standard	CBDTM/THERP
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, decide)
		Timing: Time available for recovery
Availability and clarity of instrumentation (cues to take actions as well as 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 vs. Monitor
		Data not attended to: Front vs. Back Panel
		Data not attended to: Alarmed vs. Not Alarmed
		Data misread or miscommunicated: Indicators Easy to Locate
		Data misread or miscommunicated: Good/Bad Indicator
		Information misleading: All Cues as Stated

Table C-4
Performance shaping factors mapping (continued)

NUREG-1792	ASME PRA Standard	CBDTM/THERP
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 Alternate in Procedure
		Information misleading: Warning of Differences
		Relevant step in procedure missed: Single vs. 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" & "OR"
		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[6] execution steps with EOM and EOC for each step

Table C-4
Performance shaping factors mapping (continued)

NUREG-1792	ASME PRA Standard	CBDTM/THERP
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[6] execution steps with EOM and EOC for each step
	Factors that could lead to dependence (e.g., common instrumentation, common procedures, increased stress, etc.) (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 C-4
Performance shaping factors mapping (continued)

NUREG-1792	ASME PRA Standard	CBDTM/THERP
Workload, time pressure, stress	All listed under SR-HR-F2 + SR-HR-G3	Stress: Plant response as expected
		Stress: Workload
		Stress: Environmental PSFs
		Data not attended to: Low vs. High Workload
Environment in which the action needs to be performed	Environment (e.g., lighting, heat, 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/equipment, carrying hoses, climbing, etc)	The specific high level tasks (e.g., train level) required to achieve the goal of the response (SR HR-F2)	THERP[6] 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, clothing such as to enter a radiation area)	Necessity, adequacy, and availability of special tools, parts, clothing, etc. (SR HR-G3)	Special Requirements: Tools
		Special Requirements: Parts
		Special Requirements: Clothing

Table C-4
Performance shaping factors mapping (continued)

NUREG-1792	ASME PRA Standard	CBDTM/THERP
Available staffing and resources	Availability of resources (e.g., personnel) (SR HR-G7)	Dependency Analysis: Available resources
	There is 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, approach for implementing procedures, (e.g., aggressive vs. 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, ERF
Consideration of "realistic" accident sequence diversions and deviations (e.g., extraneous alarms, failed instruments, outside discussions, sequence evolution not exactly like that trained on).		Data not available: Indication Available in Control Room
		Data not available: Indication Accurate
		Information misleading: All Cues as Stated

C.3 Post Initiator EPRI HFE Analysis Framework

The EPRI approach for quantification of post-initiators HFEs (regardless of the initiators (fire, internal events, or flood all use the same framework)) is to classify the HFE as two parts 1) detection, diagnosis, and decision phase and 2) an action phase. In the first phase there are three possible outcomes, a mistake (P1), a non-response (P2) and a correct response. In the second phase, there are two possible outcomes, a slip (P3) and a correct action. This representation is diagramed in Figure C-1 for the purpose of quantification.

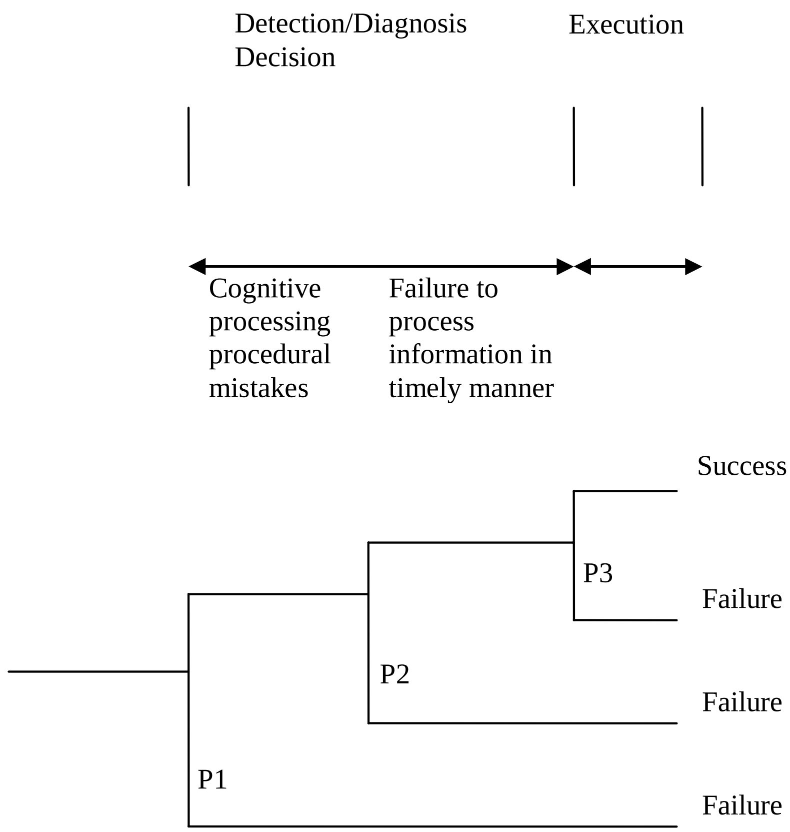


Figure C-1
Post-initiator general HFE analysis framework

This event tree format provides a natural vehicle for use of the ORE data. Because the HCR/ORE correlation is fitted to successful response times, it provides a characterization of the variation in time over which a correct detection, diagnosis, and decisions are made. In the figure C-1, P1 is quantified using CBDTM, P2 is quantified using HCR/ORE, P3 is quantified using THERP and the total HEP is the sum of all three probabilities.

For existing EOP actions, which were previously modeled in the EPRI HRA methodology the HFE analysis follows this framework. For existing EOP actions not modeled in the EPRI HRA methodology, this is not necessarily true, and the base case must first be quantified in the EPRI HRA methodology and then modified to account for fire impacts. For fire response actions, if the EPRI HRA methodology is used for quantification the analysis will follow this framework.

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 anyone 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.

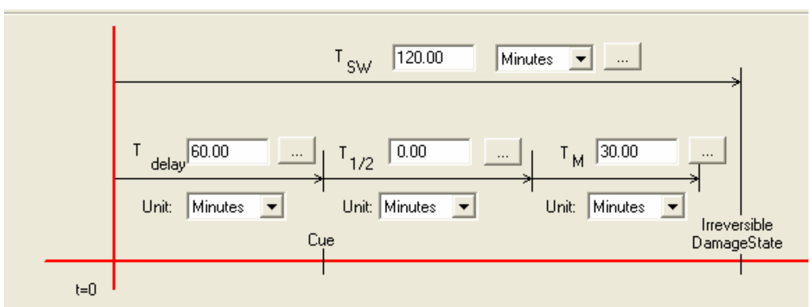
- There is not enough time to complete the action. In EPRI terms this means T_{sw} is less that the sum of T_{delay}, $T_{1/2}$ and T_m
- There is not enough crew available to complete the action within the required time
- There are no cues for diagnosis. The EPRI approach bases quantification of cognition on identification and interpretation of the cues. If the fire fails all the instrumentation required for diagnosis then there is no reason to expect the operator will respond correctly fire PRA

C.4 Timing and Crew Response Structure

Developing the timeline is fundamental to understand the EPRI approach. The EPRI HRA method applies the following definitions for time regardless of the method used for quantification:

- T_{sw} = System time window – This is defined as the time from reactor trip to an undesired end state.
- T_{delay} = Time from start of fire (or transient in the internal events case) 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 Standard Requirements HR-G4 and HR-G5 and is shown below.



The HCR/ORE studies identified the three types of actions based on cue response structure and the timeline development.

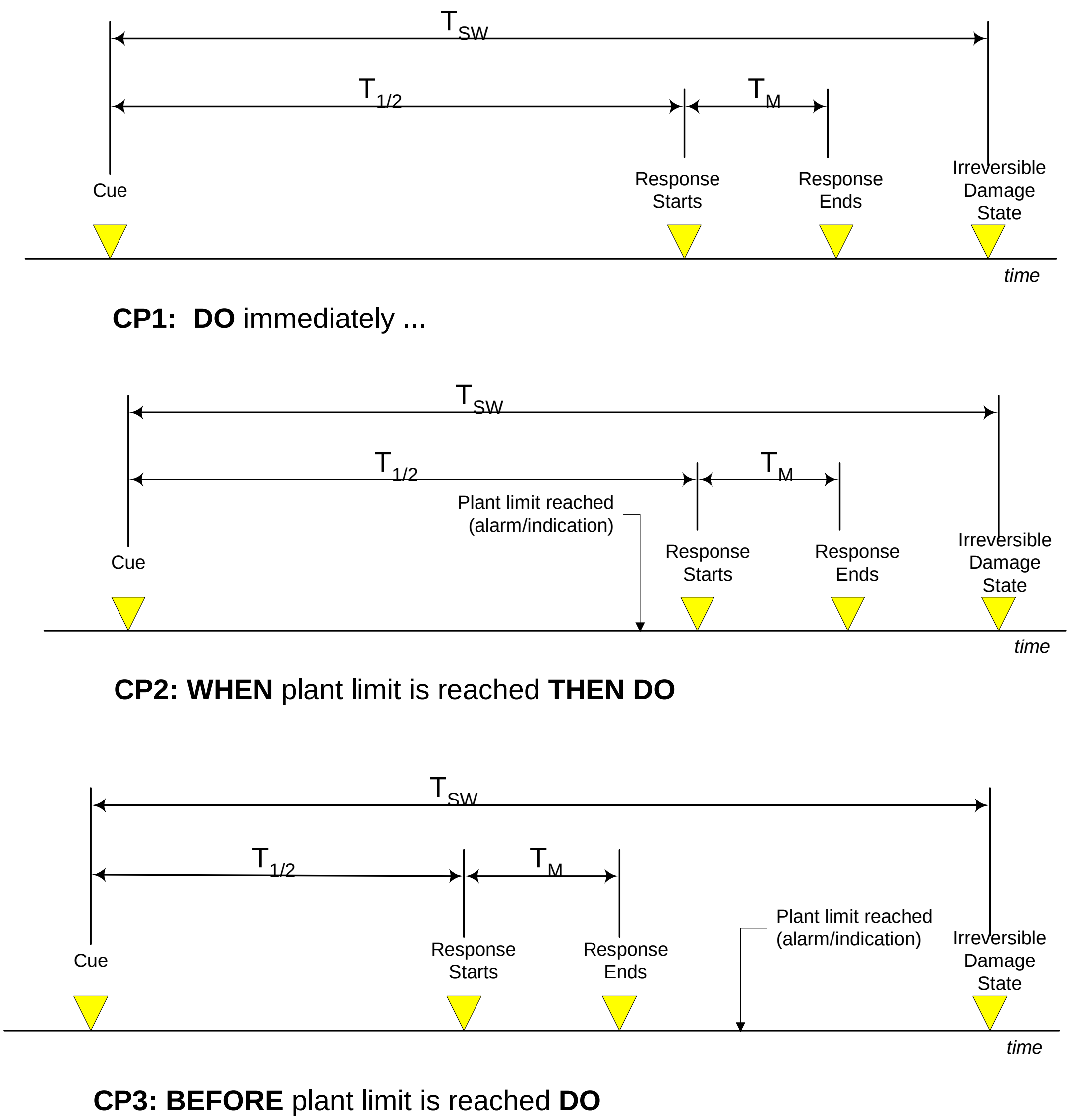


Figure C-2
Cue-response structure timelines for type CP operator actions

CP1 HFEs are simple proceduralized actions and **if** the cue is received the operators will respond to it. An example of would be a procedure step that reads "Check AFW flow, if no flow then start AFW pump."

CP2 HFEs are actions where the operators receive an alert but must delay implementation until a specific plant parameter is reached. An example would be when the cues for feed and bleed are stated early in the procedure and the operators are directed to continue with procedure **until** SG level reaches a specific point, When the SG level limits are reached then the operators perform feed and bleed. CP2 actions require that the operators are instructed to perform an action **when** and not before a plant limit is reached.

CP3 HFEs are actions where the operators must diagnosis 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 loss of all AFW and the operators must complete this action before the cues for feed and bleed are reached.

The HCR/ORE correlation uses these classifications to determine sigma which is a measure of crew to crew variability.

C.5 Instrumentation Impact on Fire HFEs

For discussion purposes there are three categories of potential instrumentation impacts on fire HFEs:

- **No impact** – All 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 information needed to evaluate the impact consists of the following:

- Is the required indication available in the control room?
  - This is successful if all indication for the specific action is available or if a minimum set of information for the specific action is available.
  - This is unsuccessful if all indication for the specific action is failed. This will be the case for total impact i.e. no instrumentation available, in which case 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 alternate information sources provided in the procedures?
  - The procedure lists alternate instrumentation to perform the specific task or provides a warning of potentially incorrect readings.
  - The procedure provides no alternate 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 where there is partial impact i.e. a minimum set of instrumentation remains available, the cognitive HEP evaluates to 5.0E-02 and no recoveries are applied.

- The operating crew has not received training in interpreting or obtaining the needed information under a fire situation. If operators do not get trained on performing the EOPs during fire scenarios, the cognitive HEP will evaluate to 0.5 for cases with partial impact on instrumentation and 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_ca and p_cd and will be discussed in detail in the following sections.

C.6 Quantification

Using the EPRI HRA methodology, it is relatively easy to modify existing internal events HEPs to reflect fire impacts. Quantification of fire response actions follows the same approach as for existing actions but there is no previous analysis to build upon 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.

C.6.1 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, since the HCR/ORE calculates very low probabilities for HFEs for which the time available is long relative to the time required. For fire HRA, instrumentations impacts, and PSF impacts can be directly addressed using the CBDTM.

In the EPRI HRA methodology, the results of the HCR/ORE and CBDTM evaluations (consistent with the internal events PRA) are used for fire HRA. The same questions that are asked for internal events HRA for quantification can be asked for fire HRA. The HRA analysts response (in many cases the selection in the decisions) will be very different between the fire and internal events case. The EPRI approach for quantification is symptom based not initiator based and thus the same questions are still applicable for fire HRA.

C.6.2 EPRI HFE Approach and Documentation

The subsections in this section follow the format of the EPRI HRA methodology. The fields described in this section are fields that are 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.

C.6.2.1 HFE Approach

To begin quantification, a new HFE needs to be created. It is good practice to setup 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 C-3 and C-4 show screen shots of the basic event data for a fire HFE. The field *Related Human Interactions*, could list the variations of the basic event (if any). For existing EOP HFEs the field *Related Human Interactions* could list the basic event from which the HFE was derived.

For fire response HFEs, a new basic event is created.

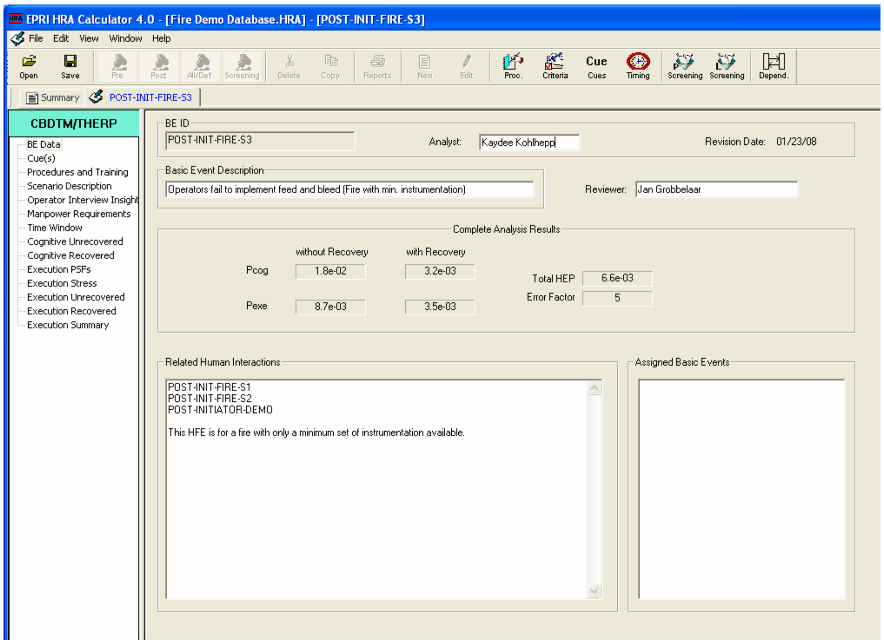


Figure C-3
EPRI HRA methodology basic event setup for fire HFE analysis

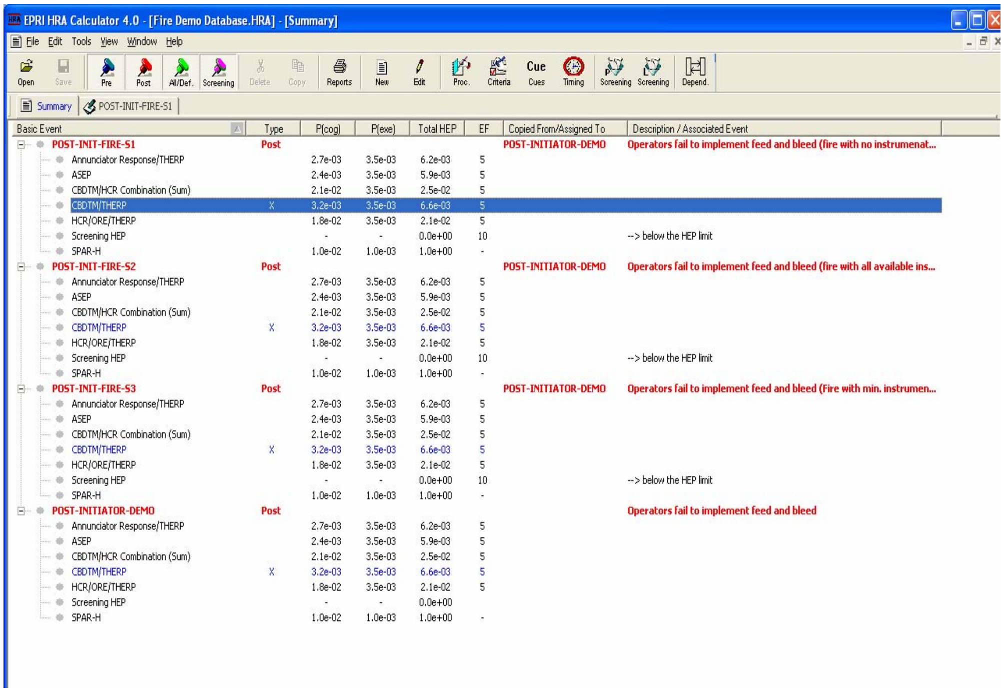


Figure C-4
EPRI HRA methodology screen shot showing multiple variations of a base case HFE

C.6.2.2 Cues

Cues are addressed in the same way in both fire and internal events HFE analyses. For fire HRA, the identification of the cues should list the specific instrumentation required for diagnosis. 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 and this list can easily be incorporated into in the component selection Task 2 of NUREG/CR-6850. Figure C-5 shows the how the identification of the cues are documented in the EPRI HRA methodology.

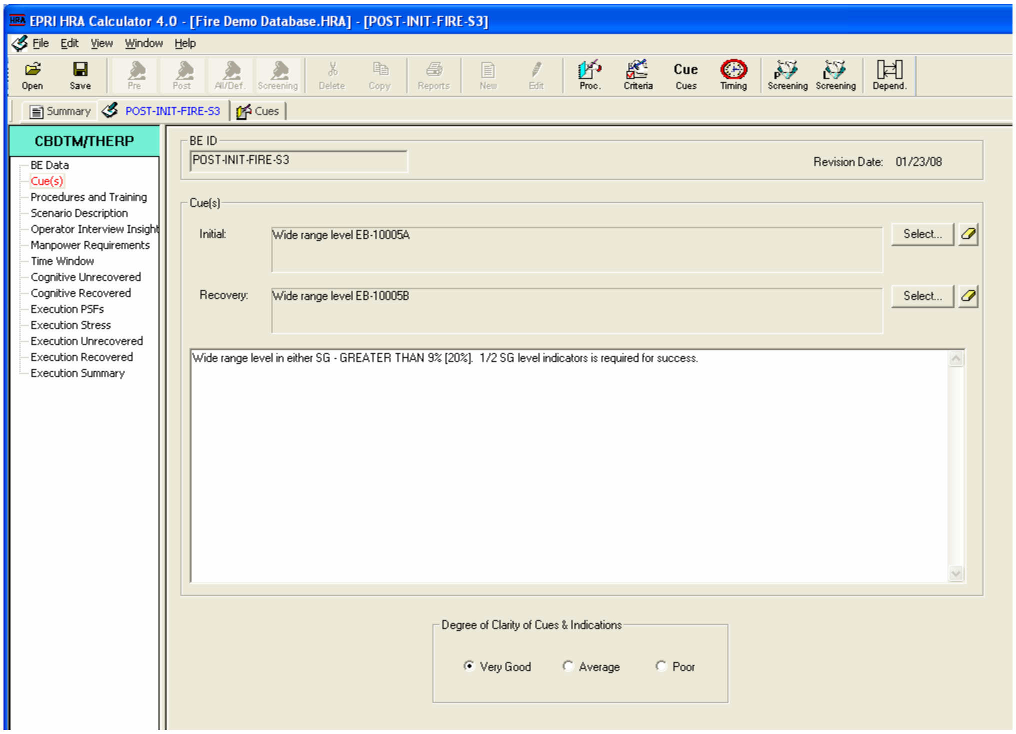


Figure C-5
EPRI HRA methodology identification of cues

C.6.2.3 Procedures

Procedures are addressed in the same way for fire and internal events HFEs. For fire HRA there maybe both an EOP and a fire procedure in use at the same time. Figure C-6 shows how the procedures are documented in the EPRI HRA methodology for a specific HFE. This window is for documentation purposes and the effects the procedures have 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 requirement HR-E2) could be added to the procedures database for documentation. The procedures database is shown in Figure C-7.

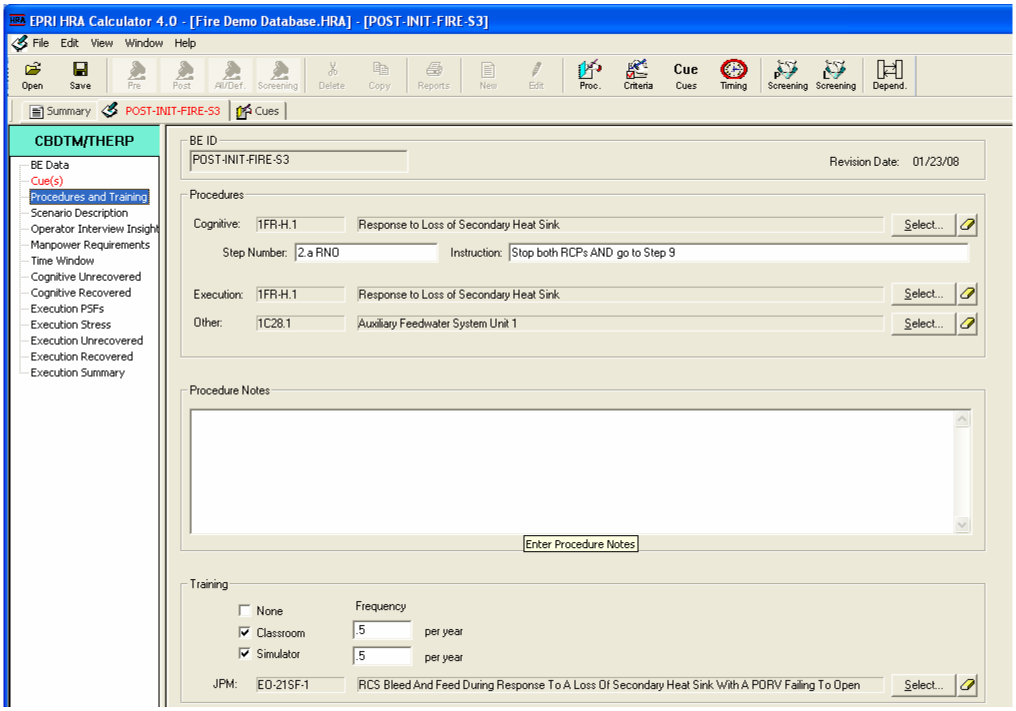


Figure C-6
EPRI HRA methodology documentation of procedures

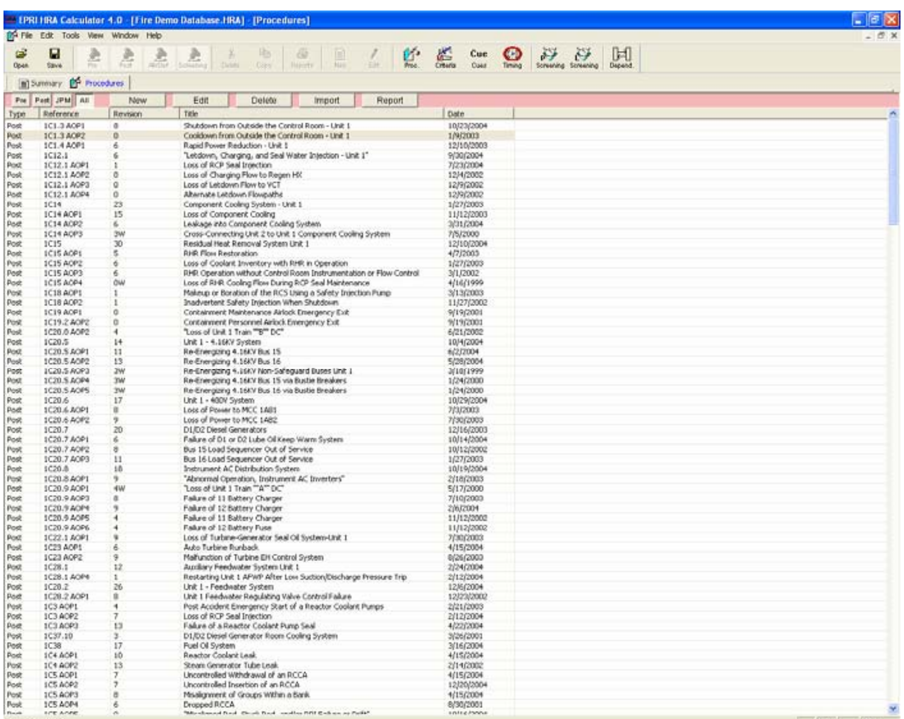


Figure C-7
EPRI HRA methodology documentation of fire procedure review

C.6.2.4 Scenario Description

The *Scenario Description* window (Figure C-8) is where the HFE is defined and documented in accordance to the ASME Standard high level requirement HR-F1. The *Identification and Definition* field should include descriptions about:

- Initial conditions,
- Accident sequence,
- Preceding operator errors and successes,
- Operator success criteria,
- Consequence of failure

Instrumentations impacts are also identified in the scenario description along with known equipment failed by the fire.

Assumptions are to be documented in the *Key Assumption* field in accordance with ASME requirement HR-I3.

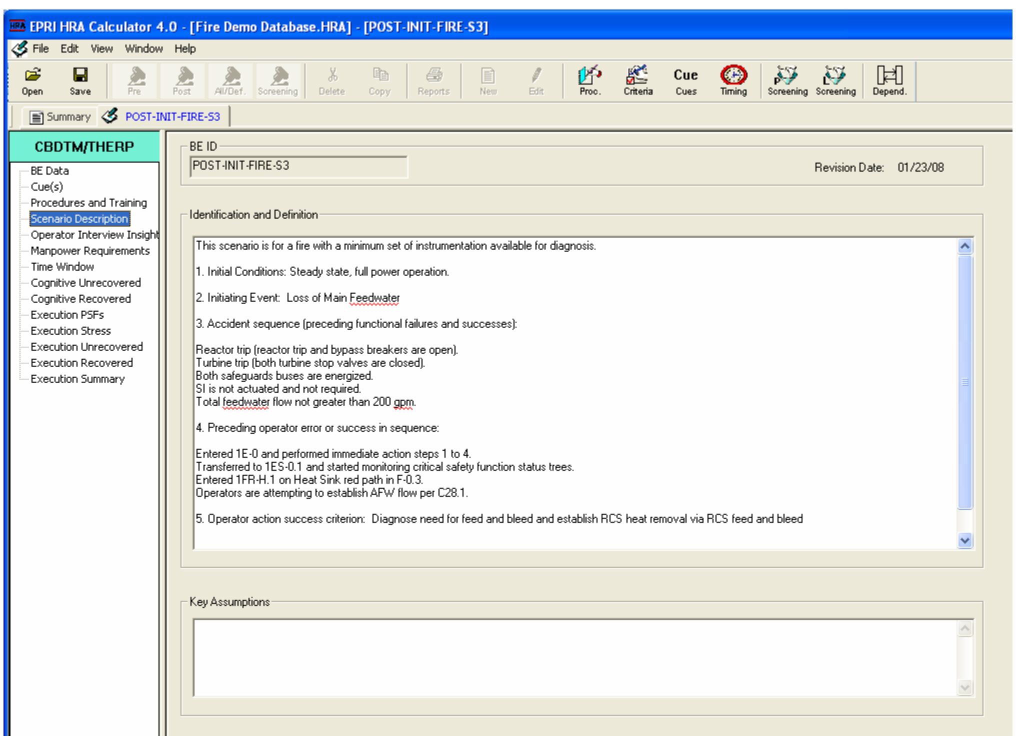


Figure C-8
EPRI HRA methodology scenario description window

C.6.2.5 Operator Interviews

The insights gained from the operator interviews are documented in the *Operator Interview Insights* window (Shown in Figure C-9) and include:

- Documentation of talk through with plant operations and training personnel to confirm that interpretation of the fire procedures are consistent with plant operation. (ASME requirement HR-E2)
- Documentation of talk-thoughts with operators to confirm the response models for the scenarios modeled. (ASME requirements HR-E3)

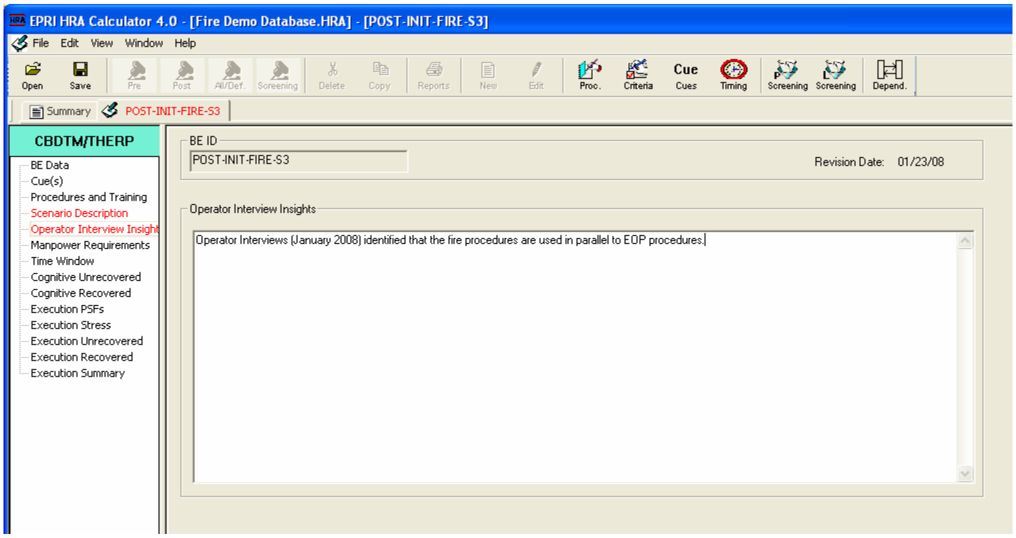


Figure C-9
EPRI HRA methodology operator interview insights window

C.6.2.6 Manpower Requirements

As part of the analysis framework (see figure C-2), the crew requirements should be identified and documented in the *Manpower Requirements* window (Shown in Figure C-10). If there is not enough crew available to complete the actions then the HEP should be set to 1.0.

It should be noted that NUREG/CR-6850 Task 12 assumes that

"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 man power 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.

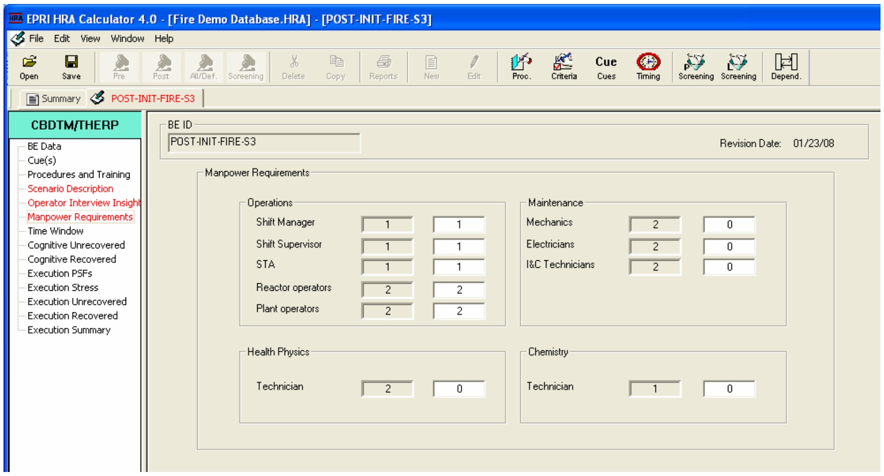


Figure C-10
EPRI HRA methodology manpower requirements window

C.6.2.7 Time

Timing is documented in the EPRI HRA methodology as shown in Figure C-11.

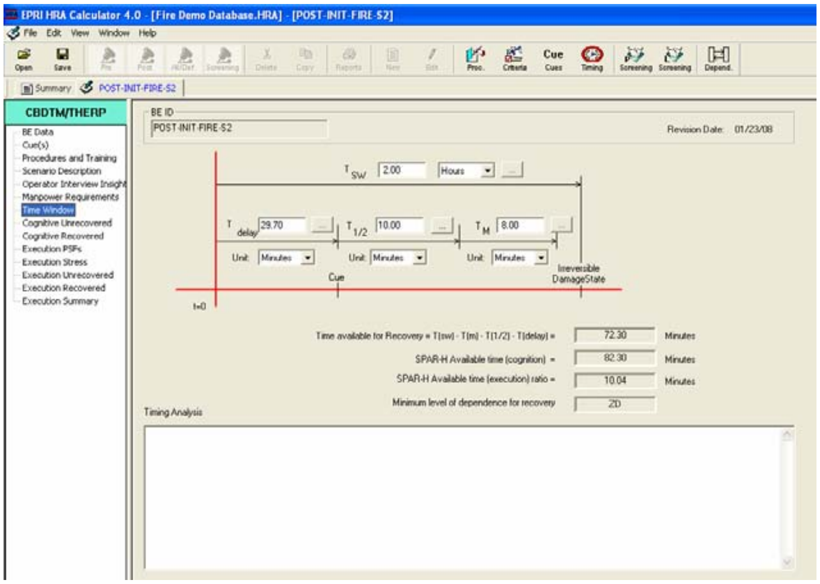


Figure C-11
EPRI HRA methodology timing window

The EPRI HRA method applies the following definitions for time:

- T_{SW} = System time window – This is usually the time from reactor trip to an undesired end state
- T_{delay} = Time from start of transient 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 Standard Requirements HR-G4 and HR-G5. For existing internal events HFEs, this field can document both the internal events timing and any adjusts made to account for the fire.

If the implementation of the EOPs is delayed due to 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,

$$T_{delay} = T_{delay\ base\ case} + 30\ \text{min}$$

The manipulation time (T_m) should account for any travel time to reach the execution location. This travel time could be significantly impacted due to the fire location. T_m can be obtained from a demonstration of feasibility, job performance measures (JPMs) or walk through or talk through with the operators. As an initial estimate for existing internal events HFEs, it is recommended to increase T_M by at least 10 minutes.

If the *Time available for Recovery* is less than zero as in the example shown in Figure C-12, the HEP should evaluate to 1.0, as there is insufficient time to perform the action.

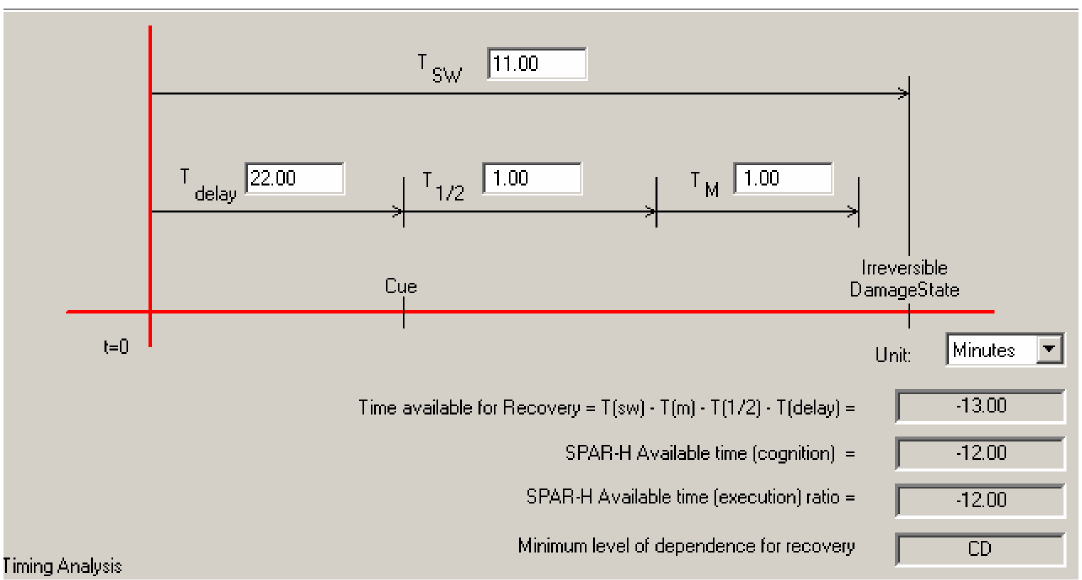


Figure C-12
Time window – time available for recovery is less than zero

C.6.3 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 some process. The CBDTM assesses HEPs by evaluating separate decision trees that evaluate each of the cognitive failure mechanisms shown in Table C-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 comprised of a four failure mechanisms.

Table C-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 fire scenario is also included.

C.6.3.1 Failure Mechanism a, Data Not Available

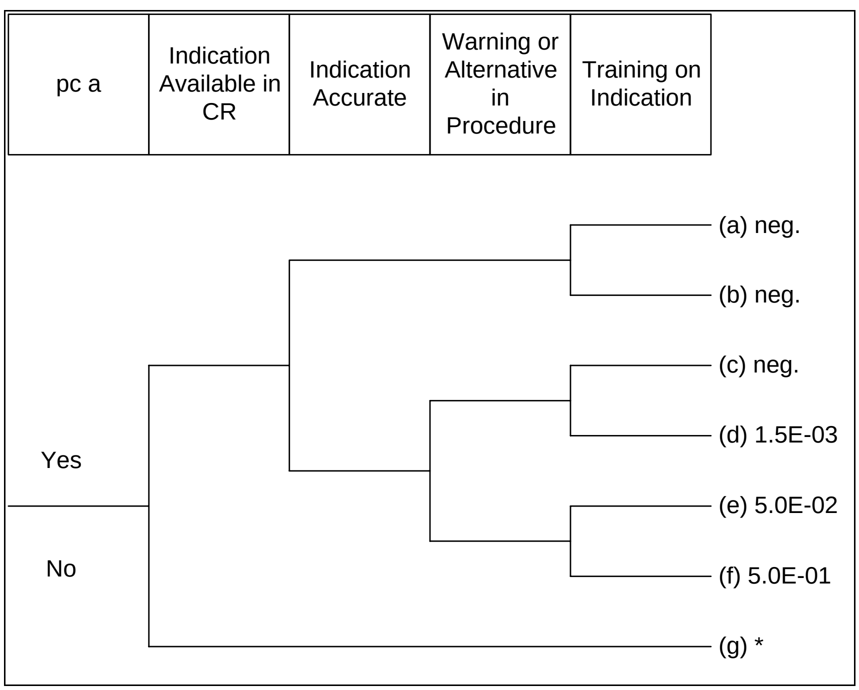


Figure C-13
Decision tree for p_ca, data not available

Table C-6
Guidance on decision nodes for $p_c a$, data not available

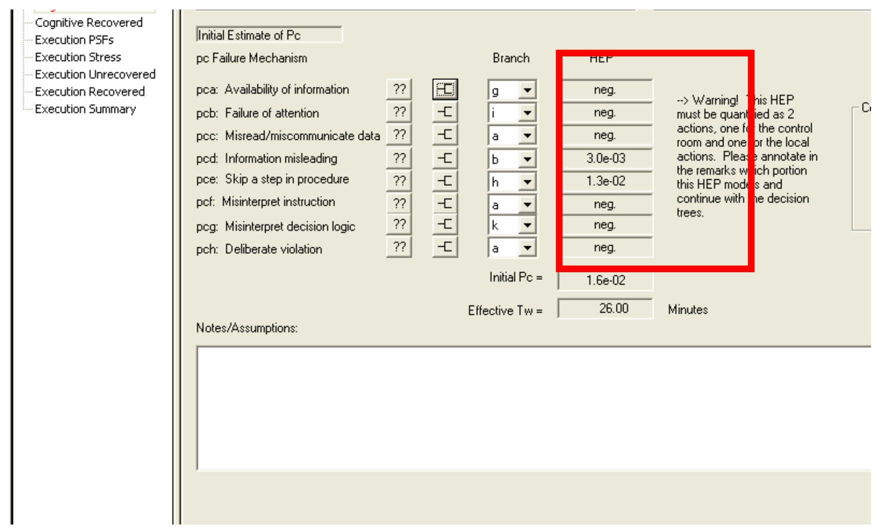
Decision Node	Guidance as Stated in EPRI TR-100259 [5]	Guidance Specific for Fire HRA
Indication Available in CR	Is the required indication available in the control room?	The yes branch is used when all indication for specific action is available or if a minimum set of information for the specific action is available. The no branch is used when all indications for the specific action are failed. This will be the case for total impact i.e. no instrumentation available, in which the case 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 control room and one for local actions. If there is no additional indicators (either in CR or locally) which can be credited for fire HRA then the HEP should be set to 1.0. The displayed branch value of 0.0 or negligible should alert the analyst that HFE being modeled is outside the scope of this decision tree and needs to be redefined.  **HRA Calculator warning when selecting decision branch g in decision tree $p_c a$.**

Table C-6
Guidance on decision nodes for $p_c a$, data not available (continued)

Decision Node	Guidance as Stated in EPRI TR-100259 [5]	Guidance Specific for Fire HRA
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) then 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 therefore the indications are assumed to be inaccurate.
Warning or Alternate in Procedure	If the normally displayed information is expected to be unreliable, is a warning or a note directing alternate information sources provided in the procedures?	The yes branch is used when the procedure lists alternate 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 alternate 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 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.

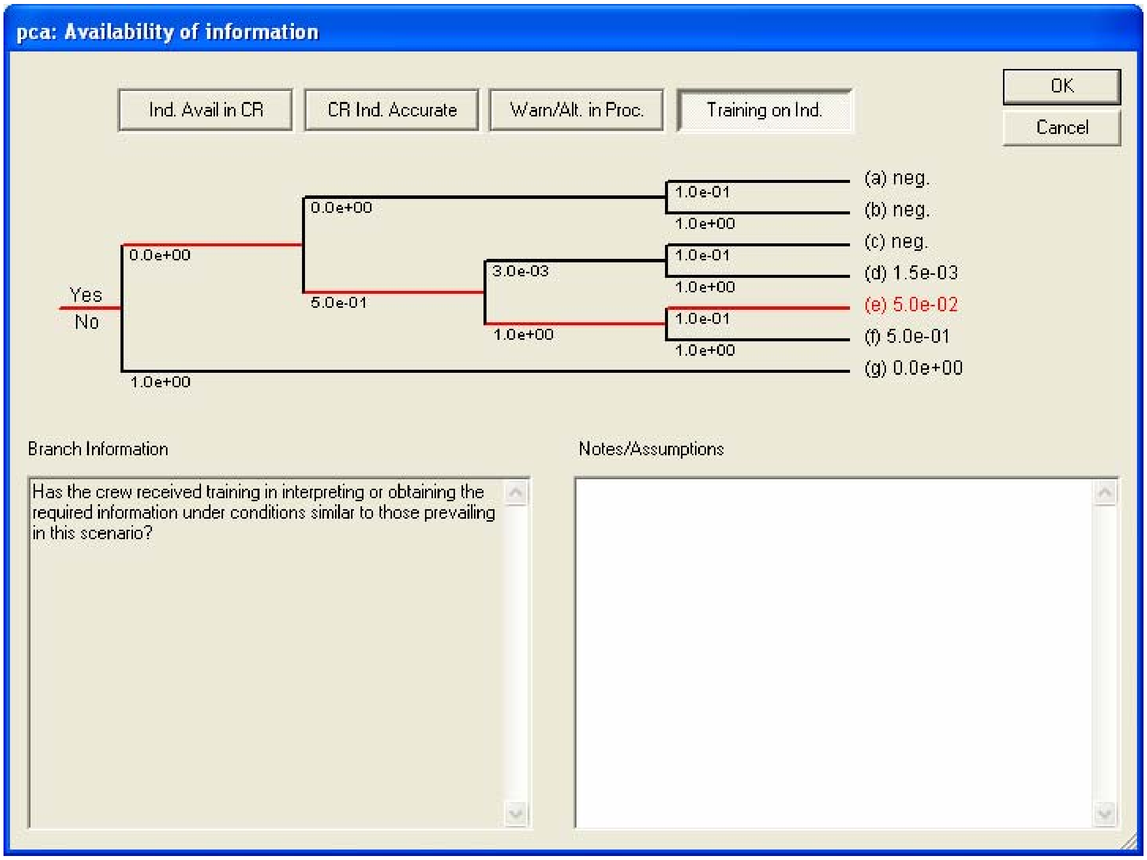


Figure C-14
EPRI HRA methodology p_ca branch selection to account for instrumentation partially impacted by fire and general training credited

C.6.3.2 Failure Mechanism b, Data Not Attended to

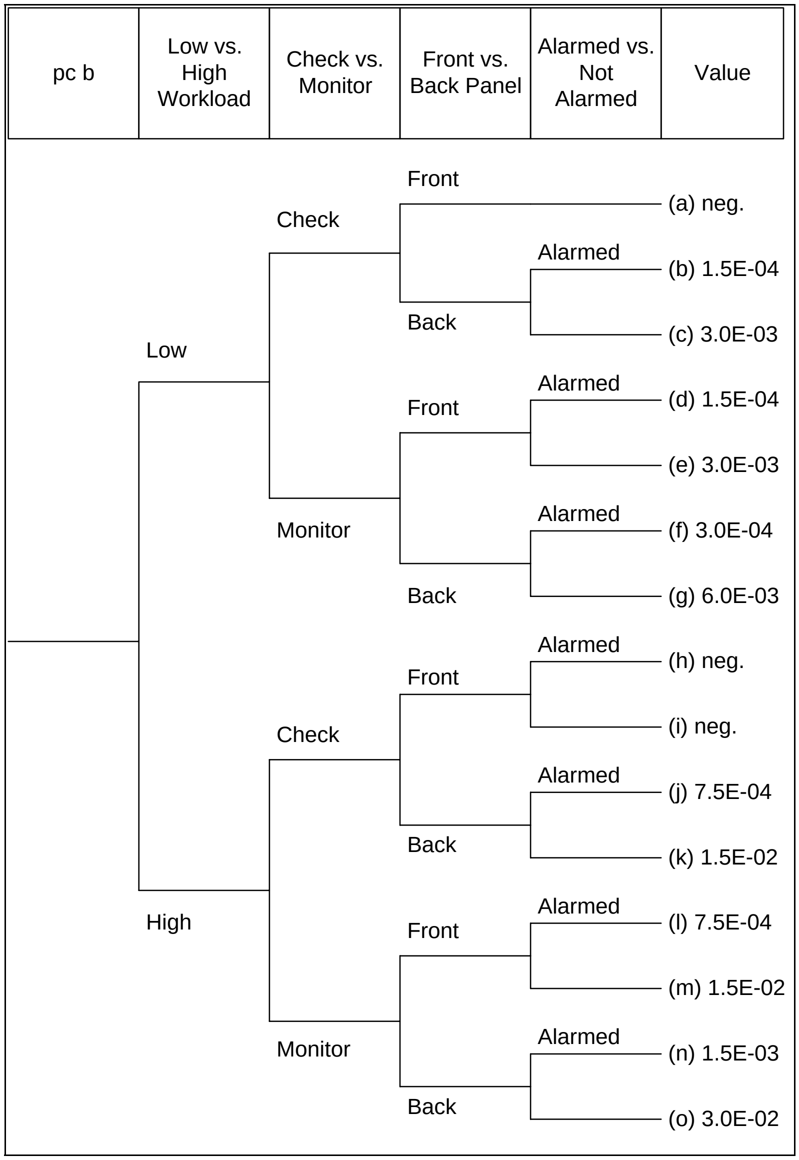


Figure C-15
Decision tree for p_cb, data not attended to

Table C-7
Guidance on decision nodes for p_cb, data not attended to

Decision Node	Guidance as Stated in EPRI TR-100259 [5]	Guidance Specific for Fire HRA
Low vs. Hi Workload	Do the cues critical to the 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 is he required to 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, he 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 only be used 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 then the alarm can not be used as a recovery and the down branch is used.

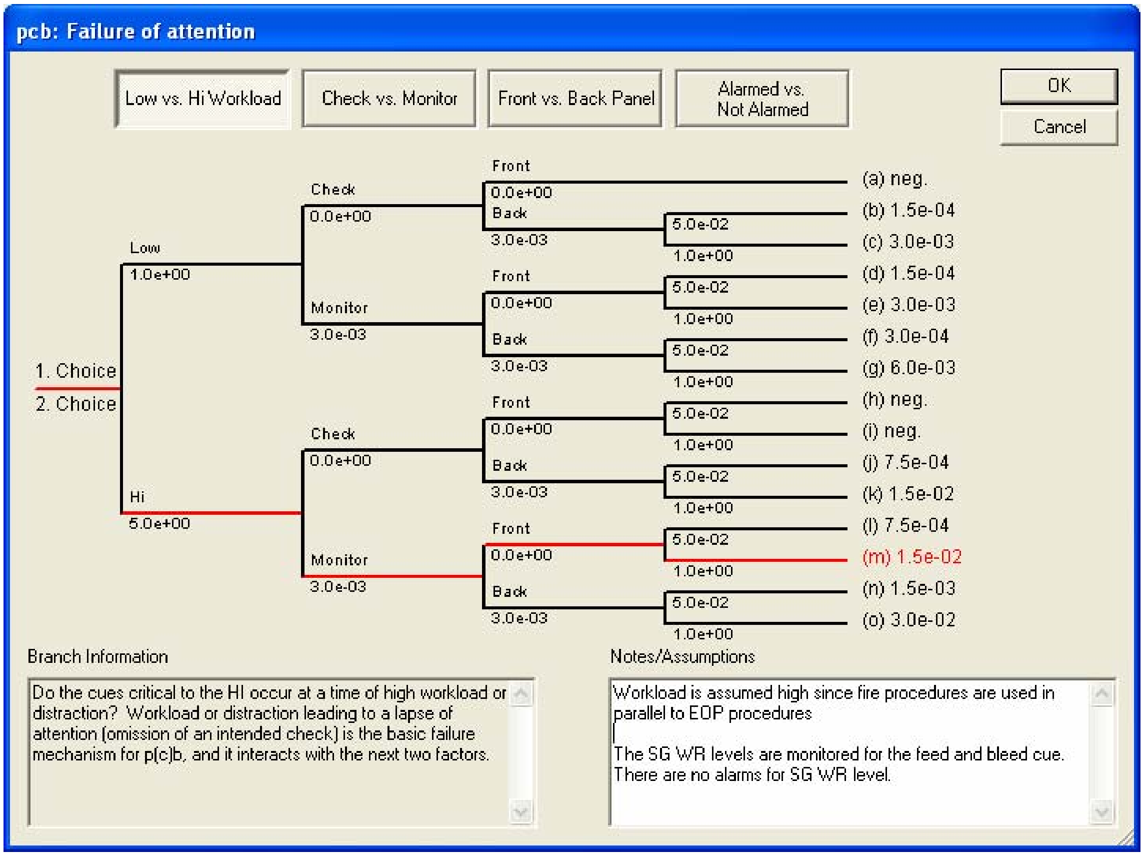


Figure C-16
EPRI HRA methodology $p_c b$ branch selection to account for high workload due to use of fire procedures in parallel to EOPs

C.6.3.3 Failure Mechanism c, Data Misread or Miscommunicated

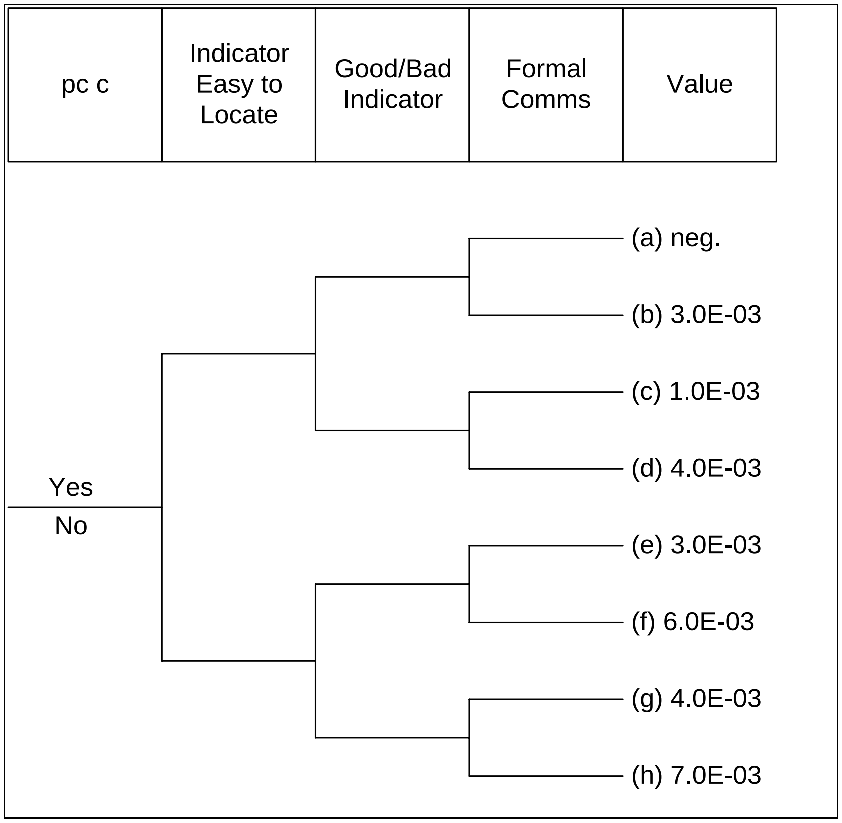


Figure C-17
Decision tree for p_cc, data misread or miscommunicated

Table C-8
Guidance on decision nodes for p_cc, data misread or miscommunicated

Decision Node	Guidance as Stated in EPRI TR-100259 [5]	Guidance Specific for Fire HRA
Indicators Easy to Locate	Is 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 with what parameter the value is associated (this limited formality is sufficient to allow the person receiving the information to detect any mistakes in understanding his request)?	If the fire requires the operators to wear breathing apparatuses then no credit is given for formal communication and the No branch is used.

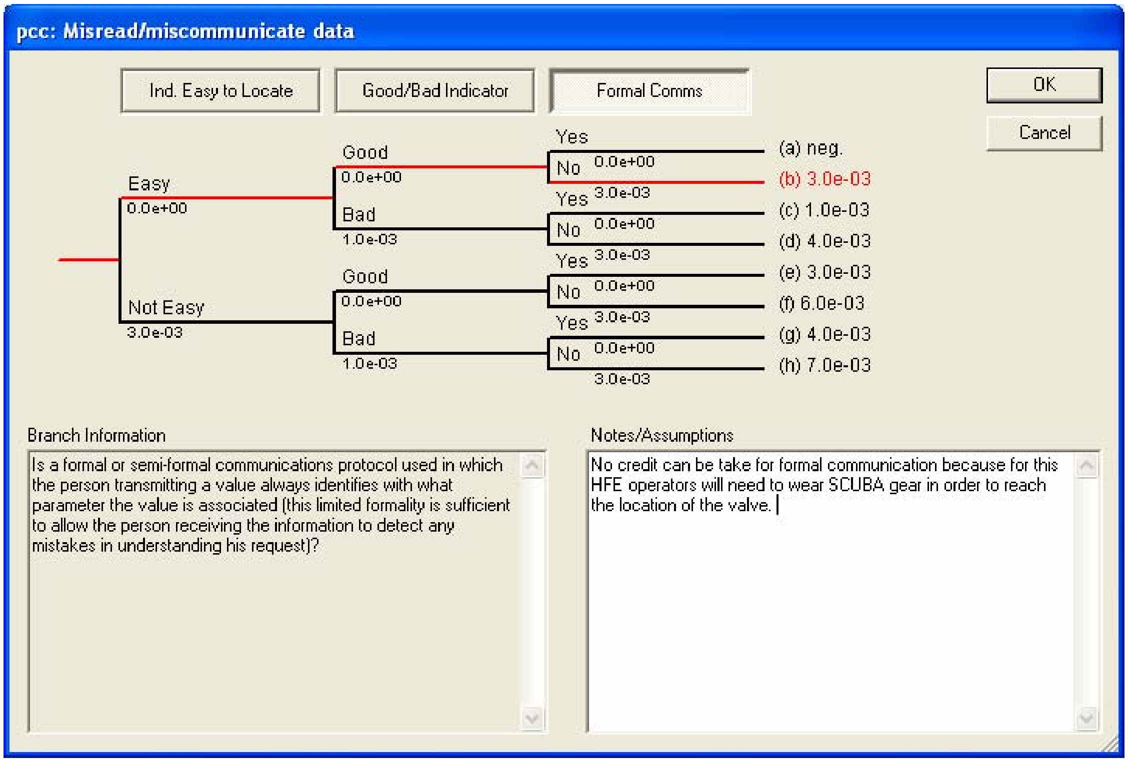


Figure C-18
EPRI HRA methodology p_cc, branch selection to account for difficulties in communication

C.6.3.4 Failure Mechanism d, Information Misleading

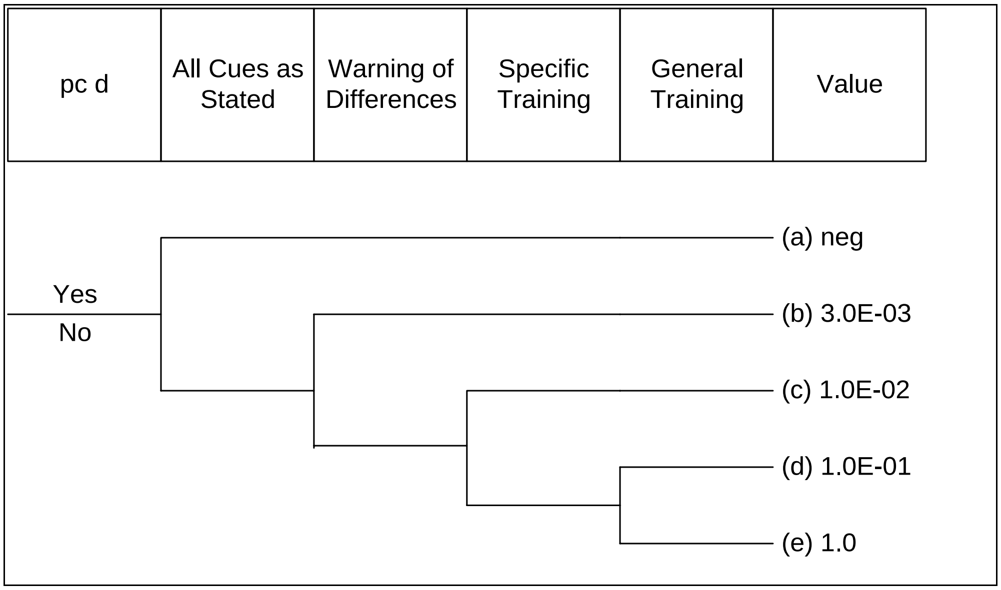


Figure C-19
Decision tree p_cd, information misleading

Table C-9
Guidance on decision nodes for p_cd information misleading

Decision Node	Guidance As Stated In EPRI TR-100259 [5]	Guidance Specific for Fire HRA
All Cues as Stated	Are cue states or parameter values as stated in the procedure? For example, if high steamline radiation is given as one of the criteria for decision or action, the steamline 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, for example, if the steamline were isolated).	If the instrumentation is considered to be fully impacted by fire then the no branch should be used. If the instrumentation is considered to be partially impacted or not impacted by fire then 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 which 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 steamline, the answer is "yes" because isolations are so common; for instrument abnormalities that only occur under 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 to 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.

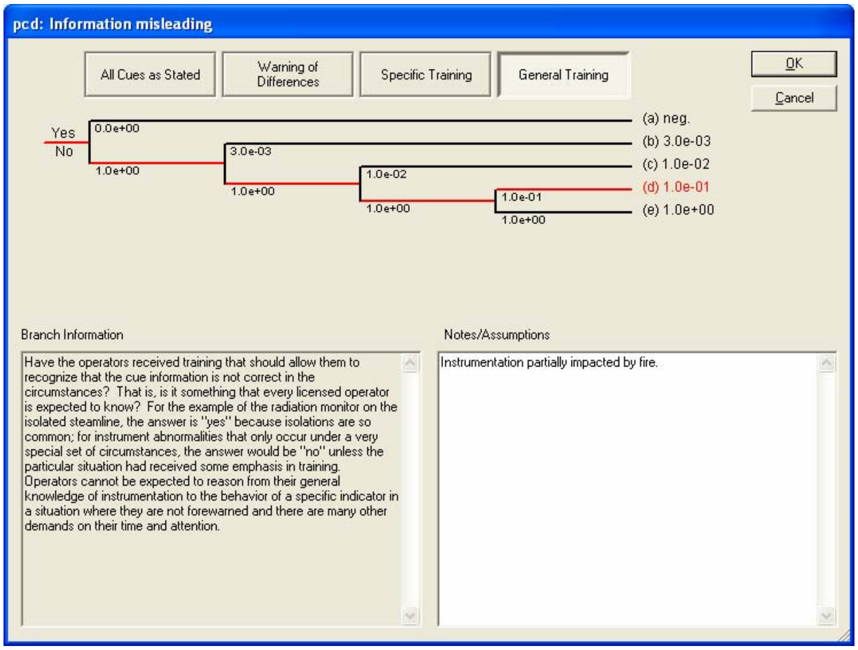


Figure C-20
EPRI HRA methodology $p_c d$ branch selection to account for instrumentation partially impacted by fire

C.6.3.5 Failure Mechanism e, Relevant Step in Procedure Missed

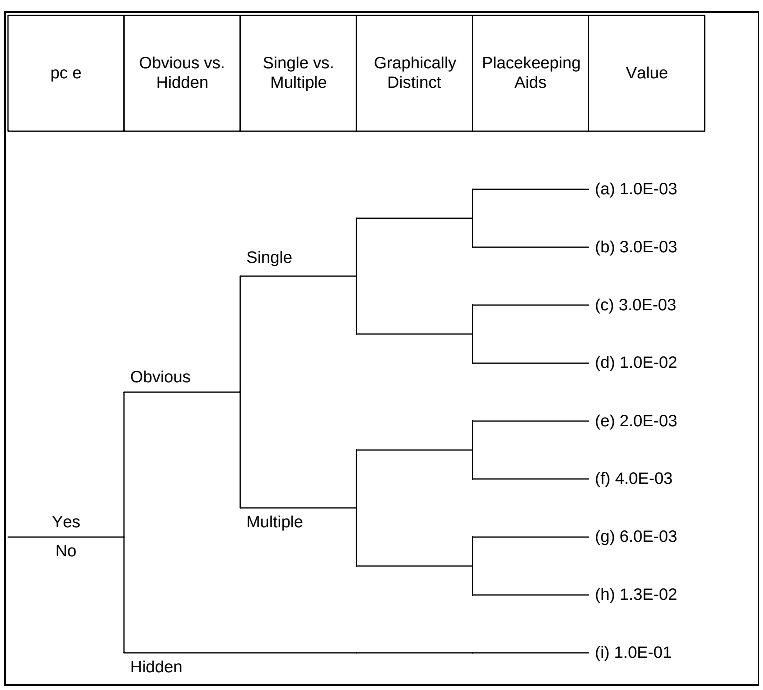


Figure C-21
Decision tree for $p_c e$, relevant step in procedure missed

Table C-10
Guidance on decision nodes for $p_c e$, relevant step in procedure missed

Decision Node	Guidance as Stated in EPRI TR-100259 [5]	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, e.g., one of several statements in a paragraph, in a note or caution, or on the back of a page?	No additional guidance for fire
Single vs. Multiple	At the time of the HI (Human Interaction), is the procedure reader using more than one text procedure or concurrently following more than one column of a flowchart procedure? If so, then 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 proceeded by notes or cautions, and steps that are formatted to emphasize logic terms are more eye-catching than simple action steps, and are less likely to be overlooked simply because the look different than surrounding steps. However, this effect is diluted if there are several such steps in view at one time (as on a typical flowchart), and for this reason the only steps on flowcharts that should be credited as being graphically distinct are those at the junction of two branching flowpaths. A procedure step is considered graphically distinct (as used in pc e) 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

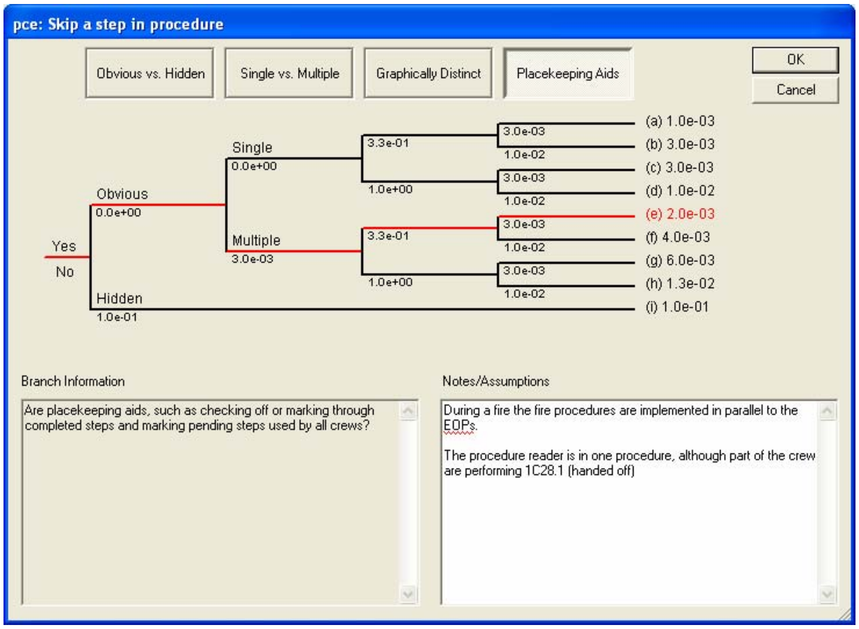


Figure C-22
EPRI HRA methodology p_ce- branch selection to account for fire procedures that are used in parallel to EOPs

C.6.3.6 Failure Mechanism f, Misinterpret Instruction

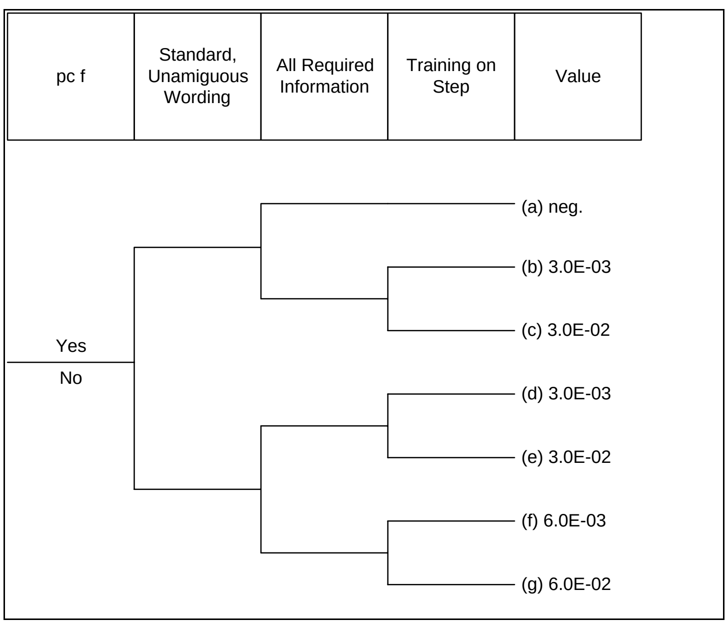


Figure C-23
Decision tree for p_cf, misinterpret instruction

Table C-11
Guidance on decision nodes for p_cf, misinterpret instruction

Decision Node	Guidance as Stated in EPRI TR-100259 [5]	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?	

C.6.3.7 Failure Mechanism g, Error in Interpreting Logic

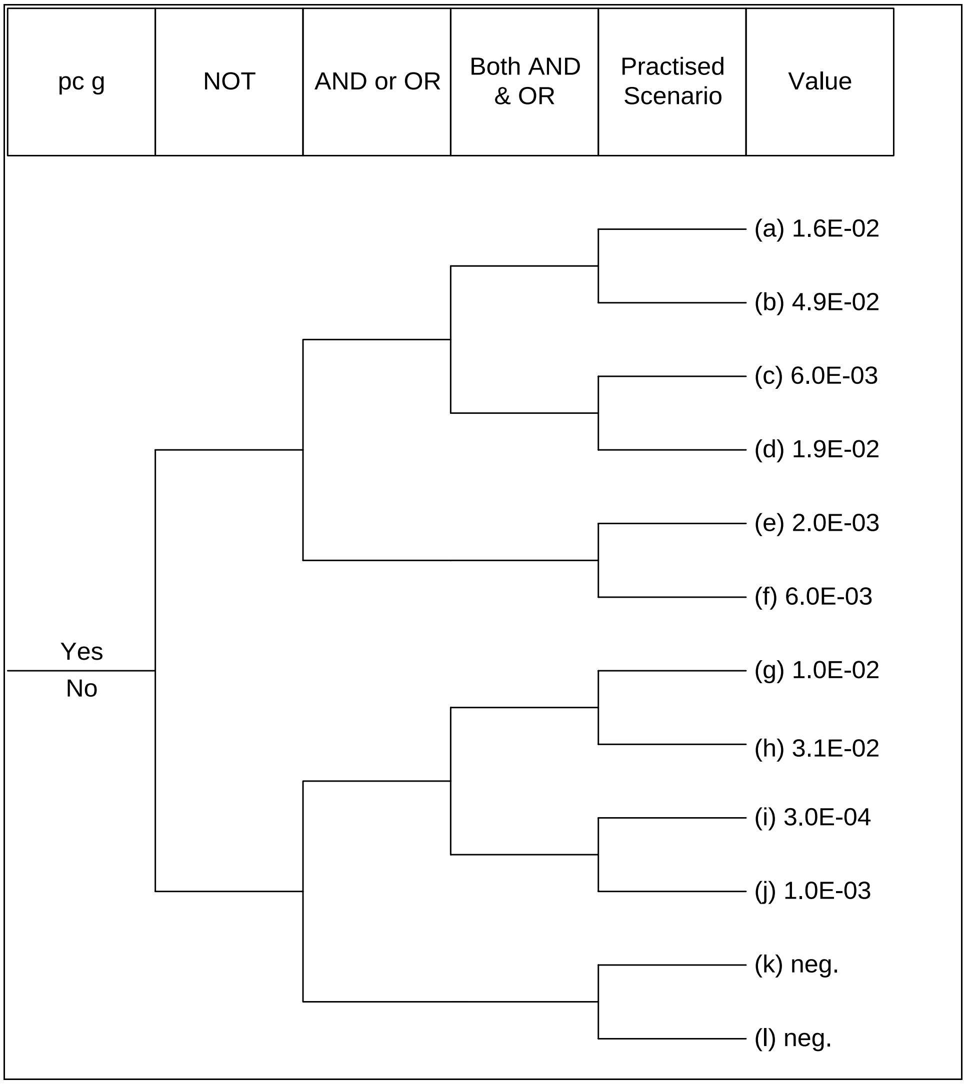


Figure C-24
Decision tree for $p_c g$, error in interpreting logic

Table C-12
Guidance on decision nodes for p_cg, error in interpreting logic

Decision Node	Guidance as Stated in EPRI TR-100259 [5]	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" & "OR"	Does the step contain a complex logic involving a combination of ANDed and ORed terms?	
Practiced Scenario	Has the crew practiced executing this step in a scenario similar to this one in a simulator?	

C.6.3.8 Failure Mechanism h, Deliberate Violation

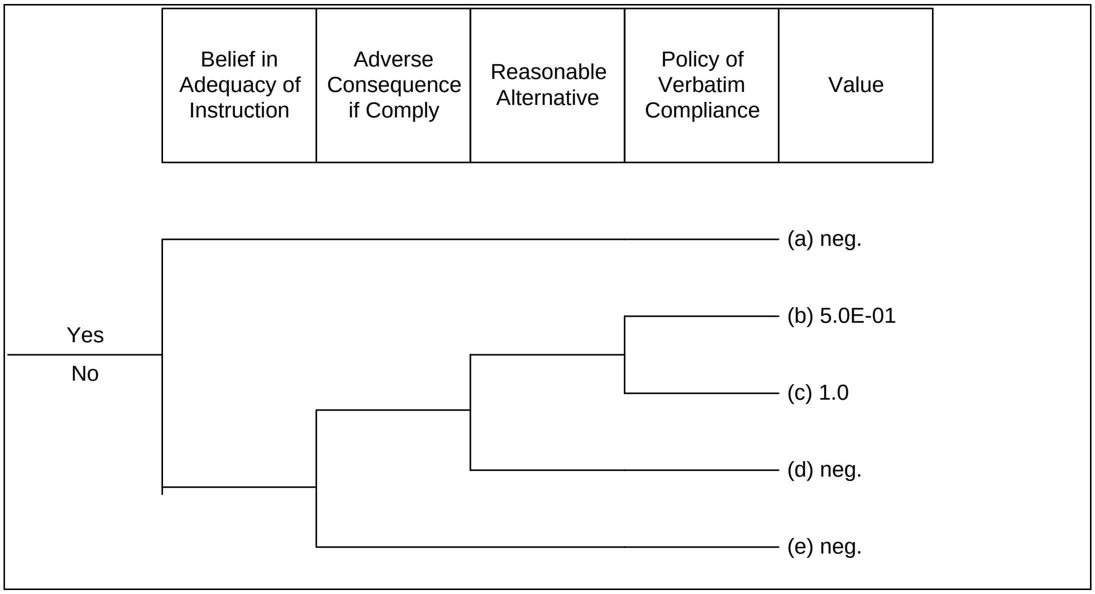


Figure C-25
Decision tree for $p_c h$, deliberate violation

Table C-13
Guidance on decision nodes for $p_c h$, deliberate violation

Decision Node	Guidance as Stated in EPRI TR-100259 [5]	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: have they 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 policy of strict verbatim compliance with EOPs and other procedures?	

C.6.3.9 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:

1. If T_{delay} is greater than the Shift Length, then Shift Change can be credited.
2. If T_{sw} is greater than or equal to 360 minutes, then Shift Change can be credited.
3. If T_{sw} is greater than or equal to 60 minutes, then ERF Review can be credited.
4. If T_{sw} is greater than or equal to 15 minutes, then STA Review can be credited.
5. 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 then the recoveries are multiplied together to obtain the value show in the Multiply By Column in Figure C-26. The dependency values are calculated using THERP.

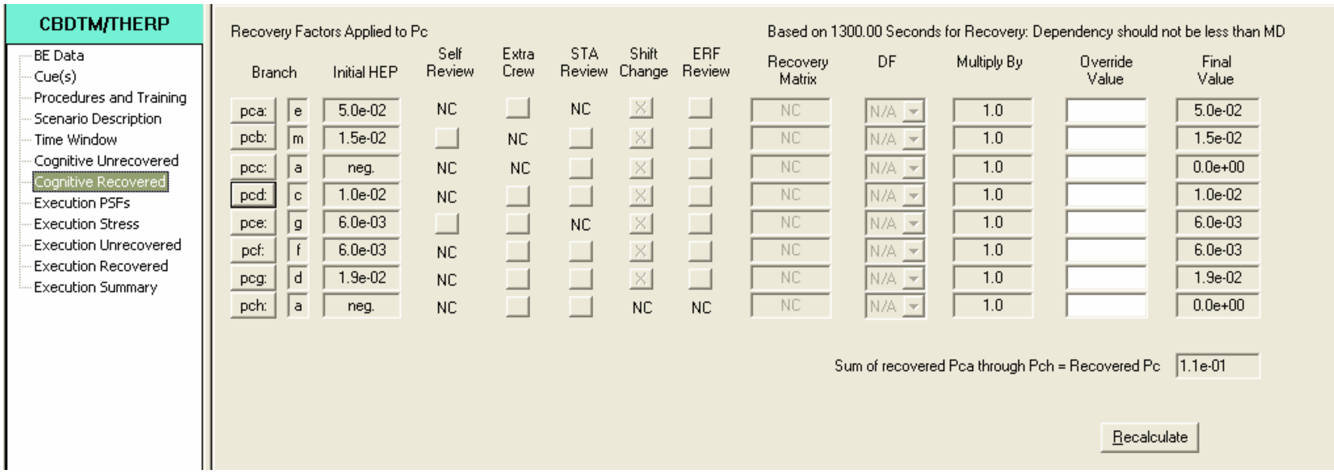


Figure C-26
Cognitive recovery

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 C-26 will be red.

If the base case applies multiple recoveries to decision tree $p_c a$ and $p_c d$, and the scenario being modeled involves impact on instrumentation then the recoveries need to be re-evaluated.

For fire response actions, the assignment for recoveries follows the same process as for internal events HRA.

C.6.4 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 long a time in comparison with the time available to respond. This contribution to the crew overall non-response is particularly important for situations where a relatively fast response to an initiator must be made. The HCR/ORE correlation is a representation of the probability of crew non-response as a function of normalized time (the normalized time is a dimensionless unit which reflects the ratio of time available to crew median response time). 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 in a time window ($T_{1/2}$) is given as follows.

$$P_c = 1 - \Phi\ [\ln(T/T_{1/2})/\ \sigma]$$

where:

Φ = the standard normal cumulative distribution (refer to standard normal distribution tables)

T = $(T_{sw} - T_m)$

T_{sw} = the time window available (either the time to boil, or time to CD)

T_m = the manipulation time, the time required to complete the needed actions once they are identified

$T_{1/2}$ = the crew median response time

σ = the logarithmic standard deviation

The timing information is defined the same 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.

Sigma (σ) corresponds to the variability in operator response, and is determined from Table 3-1 in Reference [5]. It is based on the type of reactor, (either PWR or BWR) and the HFE categorizations as 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). Figure C-27 and Figure C-28 below shows how the HCR/ORE is implemented in the EPRI HRA methodology.

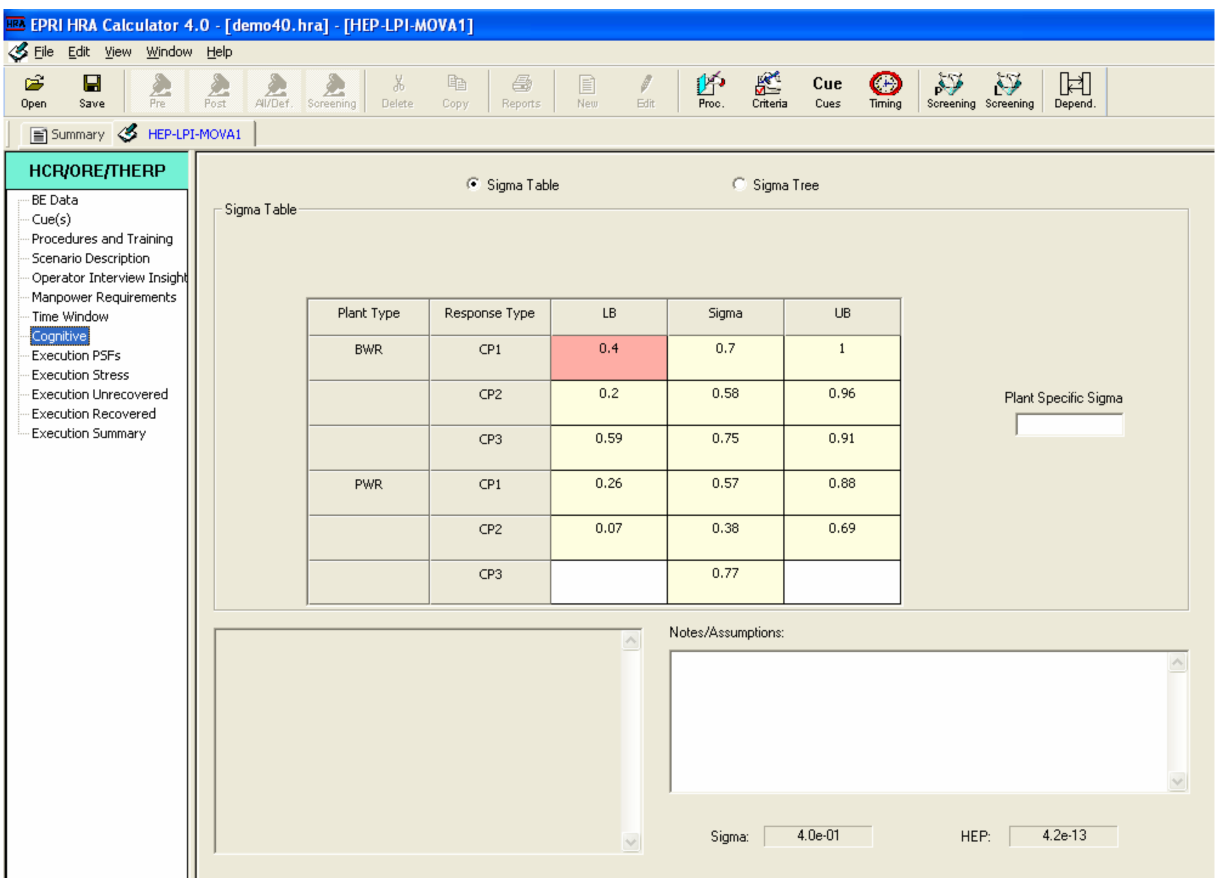


Figure C-27
HCR/ORE sigma modeling in HRA methodology

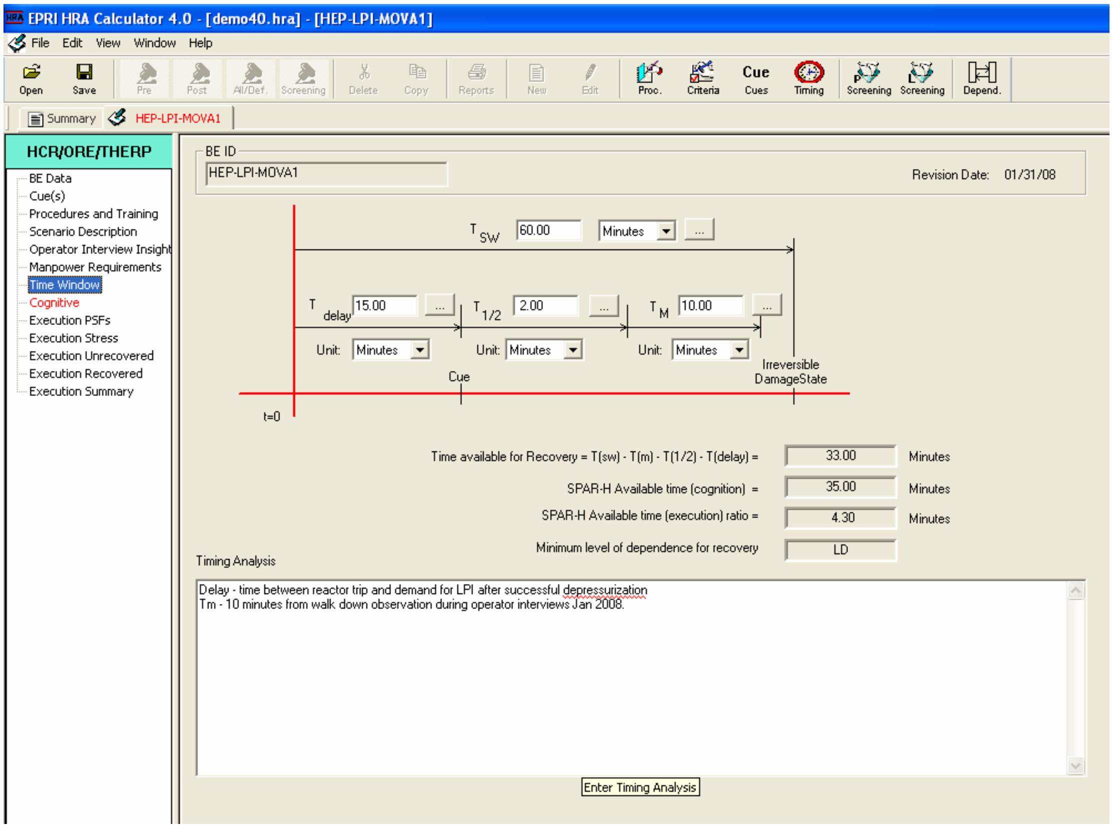


Figure C-28
Timing information in the EPRI HRA methodology

C.6.4.1 Estimation of σ for Fire HRA

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 upper bound can be used when the crew response is less certain such as cases where the primary cues are impacted and the operators must identify secondary cues to perform the action. The selection of secondary cues could vary significantly among crews and/or the time it would take to identify the cues would vary among crews. The lower bound can be used for cases where there is little crew variation expected such as the initial response to a reactor trip.

For existing internal events HFEs, the same sigma value can be used for the HFE in a fire context - provided that there is no impact on instrumentation and hence cognition. If some of the instrumentation is impacted then the upper bound sigma is used.

For fire response actions which 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 of when and or how the fire procedures will implemented then the upper bound sigma is used. For typical U.S plants the main control room abandonment criteria is defined to be at the discretion of the shift manger, STA or other high level manager and this is one example where the upper bound would be used.

Table C-14 shows the corresponding sigma values to be use for fire HRA.

Table C-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 5	0.77	**	0.5	1.2

Note 1: The standard deviation was calculated from data presented in EPRI-TR100259 [5].

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 5: For PWR CP3 actions there is only 1 data point in the original data set. Thus no distribution can be calculated. Instead overly conservative estimates are presented and are to be used with caution.

C.6.5 Execution Modeling

Execution is modeled in the EPRI HRA methodology using THERP.

C.6.5.1 PSF Execution

The execution PSFs modeled in the EPRI HRA methodology are shown Figure C-29 below.

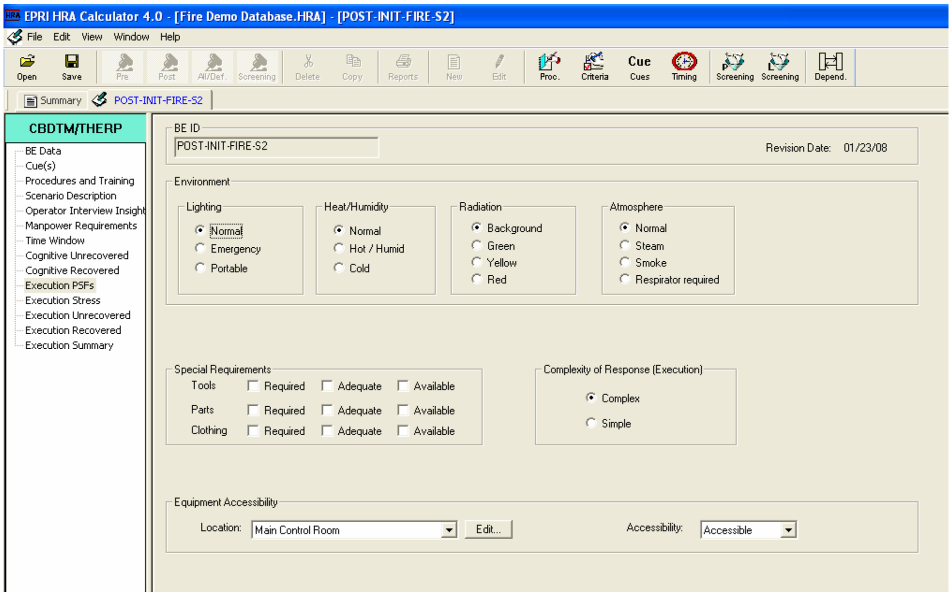


Figure C-29
EPRI HRA methodology execution PSFs

For fire HRA if the smoke will impact the operators then the smoke PSF should be checked and consequently the stress level will be at least moderate to high.

If the operators have to travel through a area in which the fire has impacted the accessibility the *accessibility* field should be set to at a minimum to *with difficulty*. If the location of the action is inaccessible due to the fire then HEP should be set to 1.0.

In the EPRI HRA methodology, if anyone of the PSFs shown above is considered negative the stress (determined in execution stress) should be at least moderate.

C.6.5.2 Execution Stress

Execution stress is determined by a decision tree shown in Figure C-30 based on workload and execution PSFs. The stress level is used as a direct multiplier to the execution probabilities and within the EPRI HRA methodology, the following multipliers are used:

- Low Stress – PSF=1
- Moderate Stress – PSF=2
- High Stress – PSF=5

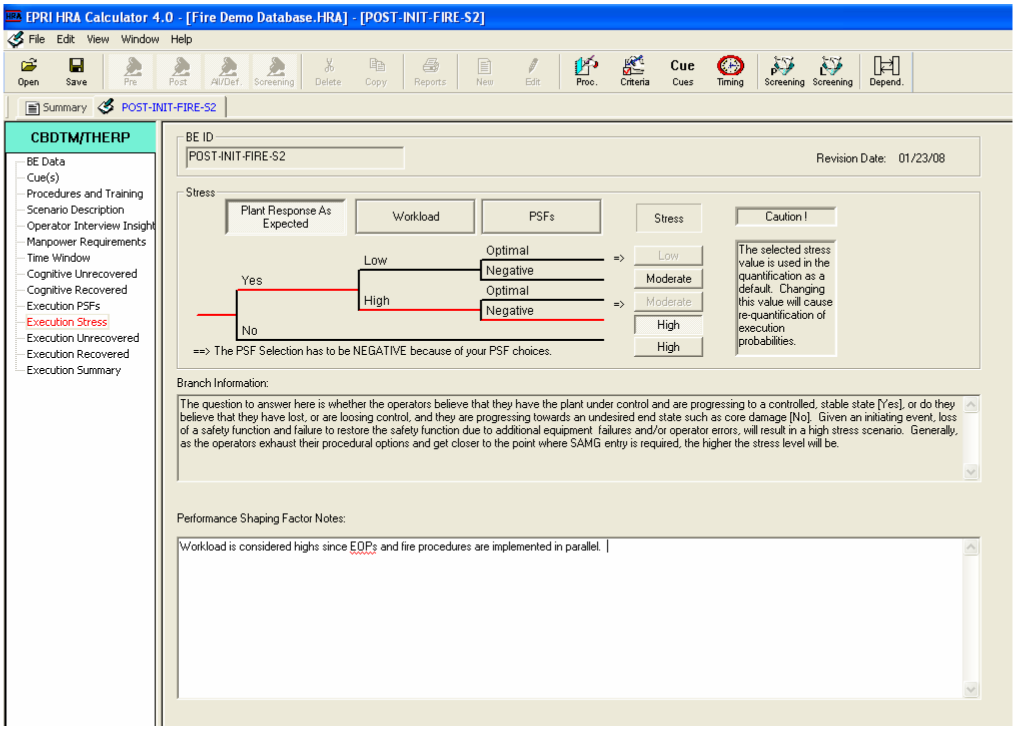


Figure C-30
EPRI HRA methodology execution stress

In addition to low, moderate and high stress there should be a fourth level of stress, Fire Stress. Fire stress (PSF=10) is not implemented in version 4.0 of the EPRI HRA methodology and should be applied externally to the EPRI HRA methodology.

For existing EOP actions, the stress levels should always be increased to a minimum of high stress. If the base case is already high stress, the fire stress must be implemented outside the EPRI HRA methodology.

For fire response actions, a high stress level should be used, if any of the execution PSFs are negative. A fire stress level should be used if more than 2 executions PSFs are negative. For fire scenarios with impeded communications the stress should be fire stress.

C.6.5.3 Execution Unrecovered and Recovered

The Execution Unrecovered and Recovered window in the EPRI HRA methodology are where each critical step is modeled and the execution HEP is quantified. The actual values used for the execution HEPs of the individual error modes are clearly situation specific, and are made on the basis of an interpretation of the instructions in THERP. Quantification of the execution part of each human error probability is based on THERP data and techniques. The various tables in Chapter 20 are utilized in determining the HEPs for the subtasks comprising 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 as documented in the EPRI HRA Calculator Software Users Manual [3], 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 completion of the local action, or lack of completion, produces a 'compelling signal' in the control room. [E.g., completing the local valve lineup for RWST refill using the 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. Values from these tables for errors of omission are divided by three based on notes in THERP Chapter 15. These notes describe adjustments to the nominal values, in particular to credit the layout of the procedures into a "response/response not obtained" format.
3. The application of recovery is included when it is judged that there is enough time for re-visitation, based on the sequence timing and time available for the human interaction. See #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 failure to read the associated instrument.
5. In determining the EOM p_e values, if the human interaction takes place within ten procedural steps from the start of the procedure, Item 20-7(1) [short list, with checkoff provisions] from THERP is used. If the human interaction takes place > 10 steps into the procedure, Item 20-7(2) [long list, with checkoff provisions] is used. Items 20-7(3) and 20-7(4) [no checkoff provisions] are usually used when the procedure is not an EOP. The start of the procedure is used vice 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 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 2 of 2 manipulations for success, p_e includes HEPs for EOC(1)+ EOC(2).
- If a human interaction required 1 manipulation, with 2 switches available, failure to manipulate the first switch can be recovered by operating the second switch: EOC(1) * EOC(2).

The Figure C-31, Figure C-32, and Figure C-33 show how the Pe is quantified within the EPRI HRA methodology.

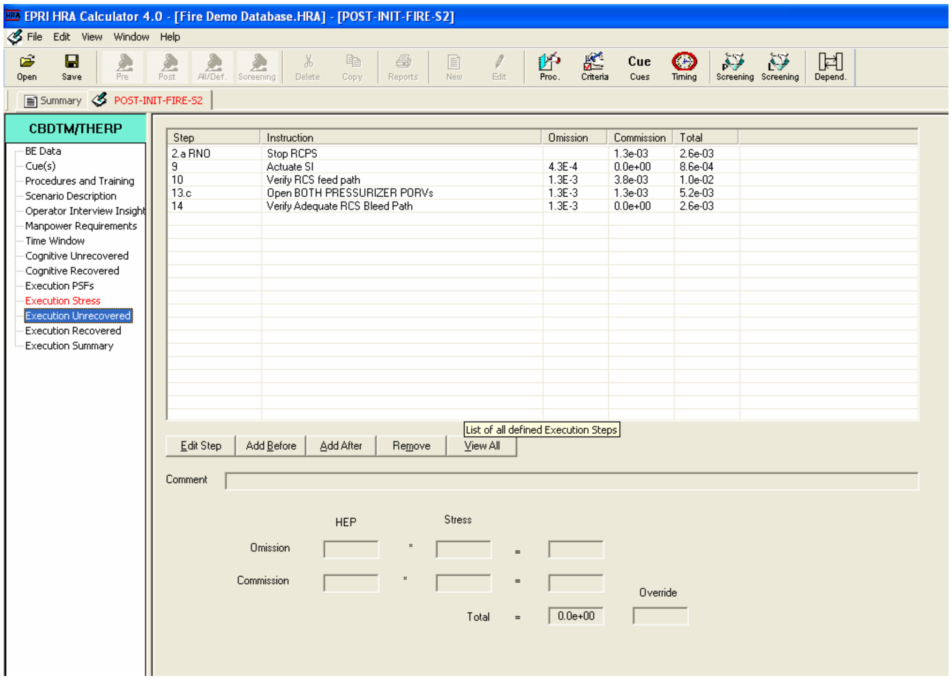


Figure C-31
EPRI HRA methodology execution unrecovered

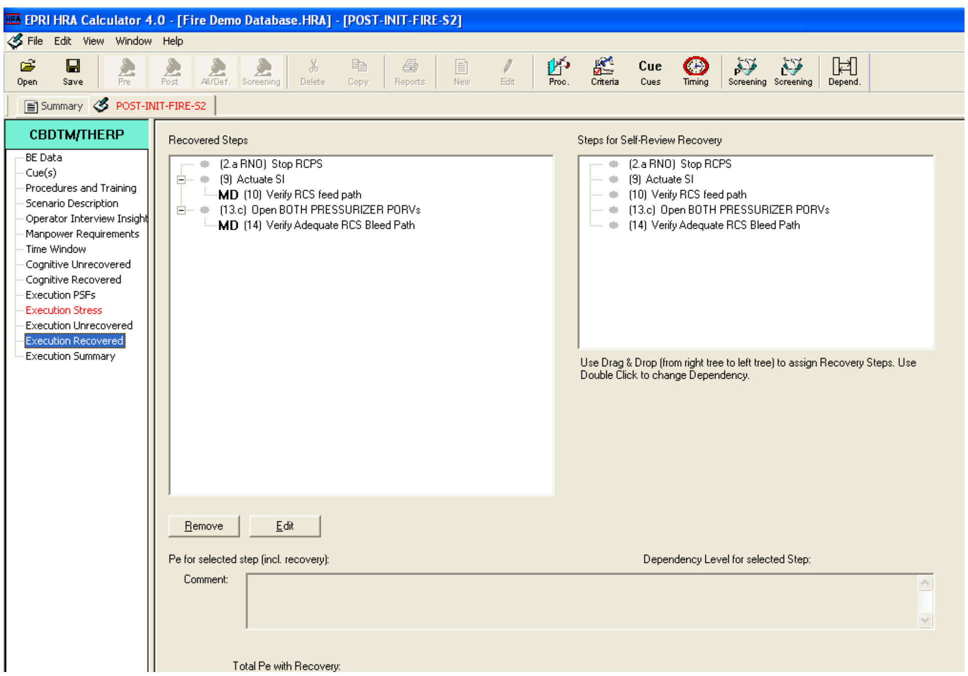


Figure C-32
EPRI HRA methodology execution recovered

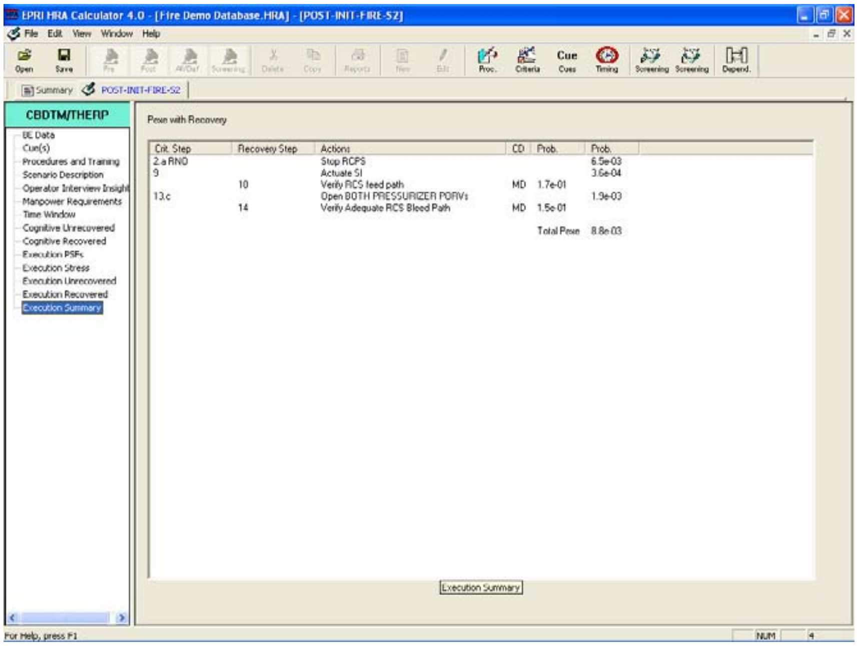


Figure C-33
EPRI HRA methodology execution summary

C.6.6 Summary Modeling Existing EOP Actions within the EPRI HRA Methodology

For existing EOP actions, it is only necessary to make small modifications from the base HFE for quantifications. The previous sections covered all the required steps to quantify and document a fire HEP 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 C-15 summarizes the previous sections and shows what needs to be modified between a base case HFE and fire HFE. Table C-15 is only applicable to existing EOP actions where the definition has not been changed for fire modeling.

Table C-15
Summary between internal events HFE and fire HFE for existing EOP actions

BE Data	The HFE Name should be a Variation of the Base Case Name to Reflect the Fire Conditions
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 need – 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 need 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 Manipulation Time (T_M) needs to be increased to account for the additional time it could take for the operators to get to the location. The travel delay is highly dependent on the fire location and if it is not know how the fire will directly affect the operators travel, is recommended that T_M be increased by 10 minutes from the base case. The 10 minutes is used as an estimated value and 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 the HEP evaluates to 1.0, as there is insufficient time to perform the action.
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 then no modifications are made to this tree. Decision tree P_cb – If the EOPs are implemented in parallel to the fire procedures then the workload is considered to be high. Decision tree P_cc – If breathing apparatus are required due to fire the communications is considered poor. Decision tree P_cd – If the fire fully impacts the instrumentation then cues are not available and HEP evaluates to 1.0. If instrumentation is partially impacted then cues are not as stated but credit can be taken for general and/or specific training. If the fire has no impact on instrumentation then the cues are not impacted by fire. Decision tree P_ce – If the EOPs are implemented in parallel to Fire procedures then 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

Table C-15
Summary between internal events HFE and fire HFE for existing EOP actions (continued)

BE Data	The HFE Name should be a Variation of the Base Case Name to Reflect the Fire Conditions
Cognitive Recovered CBDTM	If the time was modified due to fire then the recoveries need to be re-evaluated 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 tree $P_c a$ and $P_c d$ the recoveries need to be re-considered.
Cognitive HCR/ORE	For fire HRA for existing internal events actions the same sigma value used for internal events HRA can be used for the fire HFE provided that there is no impact on instrumentation. If some of the instrumentation is impacted then the upper bound is used. If the fire fully impacts the instrumentation then cues are not available and HEP evaluates to 1.0.
Execution PSFs	Check to ensure that for local actions, the location is still accessible due to fire. If not accessible then HEP = 1.0 If two are more executions PSFs are negative. For fire scenarios which impeded communications or smoke is present such that it will impact the operator performance the stress should be fire stress.
Execution Stress	Set the stress to high or fire stress. Fire stress is an additional multiplier of 2 to P_{exe}.
Execution Unrecovered	No changes are need
Execution Recovered	No changes are need

C.6.7 Summary 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 C.1 thru C.6.5.6 are applicable to all type 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 C-16 below summarizes the key parameters that are unique to fire response actions.

Table C-16
Summary of fire response actions

EPRI HRA Methodology	Fire Specific Parameters to Included in HFE Analysis
BE 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 they intend to follow the fire procedures step by step then crediting the step in the fire procedure as the cue would be appropriate. However, there are many cases where 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 to alert 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 procedure 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 will be needed. The first will be to understand the general fire response and then a second set will be needed 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 detection of a fire.
Time window	For local actions, the manipulation Time (T_M) should account for travel time to reach 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, as there is insufficient time to perform the action.

Table C-16
Summary of fire response actions (continued)

EPRI HRA Methodology	Fire Specific Parameters to Included in HFE Analysis
Cognitive Unrecovered CBDTM	Decision tree P_ca – If the fire fully impacts the instrumentation then 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 then no modifications are made to this tree. Decision tree P_cb – If the EOPs are implemented in parallel to Fire procedures then the workload is considered to be high. Decision tree P_cc – If breathing apparatus are required due to fire the communications is considered poor. Decision tree P_cd – If the fire fully impacts the instrumentation then the cues are not available and HEP evaluates to 1.0. If instrumentation is partially impacted then cues are not as stated but credit can be taken for general and/or specific training. If the fire has no impact on instrumentation then the cues are not impacted by fire. Decision tree P_ce – If the EOPs are implemented in parallel to fire procedures then multiple procedures are used. Decision tree P_cf – Use same guidance as for internal events Decision tree P_cg – Use same guidance as for internal events Decision tree P_ch – Use same guidance as for internal events
Cognitive Recovered CBDTM	Use same guidance as for internal events
Cognitive HCR/ORE	For fire response actions which 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 of when and or how the fire procedures will implemented then the upper bound is used.
Execution PSFs	For fire response actions, a high stress level should be used if any of the execution PSFs are negative. A fire stress level should be used if more than 2 executions PSFs are negative. For fire scenarios which impeded communications or smoke is present such that it will impact the operator performance the stress should be fire stress. Ensure that for local actions, the room is still accessible due to fire. If components required for manipulation are not accessible due to fire then the HEP evaluates to 1.0
Execution Stress	Set the stress to high or fire stress. Fire stress is an additional multiplier of 2 to P_{exe}.
Execution Unrecovered	Use same guidance as for internal events.
Execution Recovered	Use same guidance as for internal events.

C.6.8 Summary 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 AOP and is implemented in the same manner as all other AOPs and thus the actions can be quantified in the same manner as AOPs actions. The same guidance for fire response actions (Table C-16) can be applied to MCR abandonment actions.

C.6.9 Summary 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 the main document. The following assumptions were made in the identification process:

1. Actions that require multiple spurious indications on difference parameters can be screened from consideration.
2. Actions that require indication on one of several redundant channels can be screen from considerations. If the action requires multiple spurious indication on redundant channels the actions can not be screened from consideration.
3. 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 then the guidance for fire response actions can be applied. If the recovery action is a proceduralized EOP action then the existing EOP guidance can be applied.

C.7 Discussion on how Fire Effects are Modeled Using the EPRI Approach

Because the EPRI approach is symptom based not initiator based is not always obvious how the specific fire effects described in Section 4, Section 4.3 are incorporated into the EPRI approach. This section provides a discussion for 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 has tried to capture some of the PSF overlap specific for fire and focused 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 method such as THERP, CBDTM, HCR/ORE, and SHAPR/SHAPR1.

C.7.1 Cues and Indications

Cue and indications can be mapped to the following parts of the EPRI approach:

- Considered explicitly in decision tree p_ca and p_cd
- Cue 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 that are 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 be credible anymore if either (1) the indications are impacted by the fire or (2) the associated instrumentation cable routing is unknown.

For discussion purposes there are three categories of potential instrumentation impacts on fire HFEs:

- **No impact** – All the 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 either by 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.

To illustrate how impacted cues are modeled, the following examples are considered.

For an internal events case, consider an action where all SG level indicators are available and reliable. For the internal events case the following branches in decision p_ca and p_cd are used and the impacts on cognition are considered negligible.

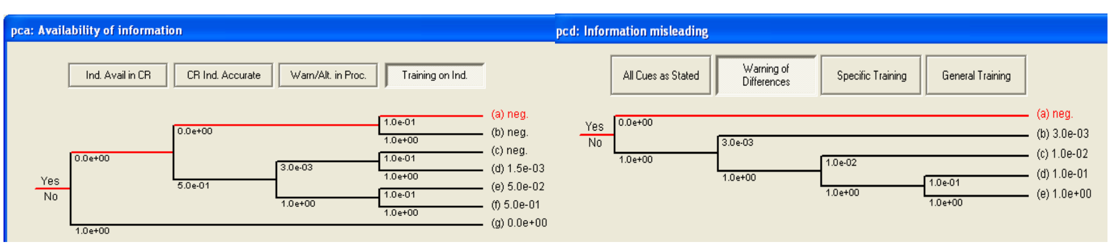


Figure C-34
Modeling of SG level indicators for internal events action in which there is no impact on instrumentation

Consider the same action for the fire case, but in the fire case 2/4 SG level indicators are failed by the fire and the choices shown in Figure C-34 are applied. In the fire case, all instrumentation required for successful cognition is available in the control room but half the instrumentation is fail by the fire and hence considered inaccurate. All the cues are not as stated because the operators must determine which level indicators are the correct. In this fire scenario the sum of decision tree $p_c a$, $p_c d$ is 1.5E-1 with no recoveries applied.

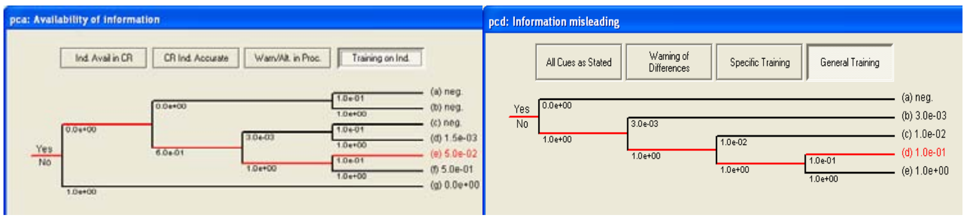


Figure C-35
Modeling to reflect partial impact on instrumentation due to fire effects

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 then crediting the step in the fire procedure as the cue would be appropriate. However, there are many cases where 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 to alert 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 require actions within the time available. The time it would take for the operators to interpret and react to partial instrumentation case is to be captured in $T_{1/2}$. In some cases the diagnosis is so complex due to a combination of spurious and failed indications that $T_{1/2}$ is estimated to take longer than the total time available to complete the action and in this case the HEP would evaluate to 1. 0.

C.7.2 Timing

The EPRI HRA method applies the following definitions for time:

- TSW = System time window – This is typically the time from reactor trip to an undesired end state.
- TM = Manipulation time
- T1/2 = Median response time

The *Timing Analysis* field documents the source of the timing in accordance with ASME Standard Requirements HR-G4 and HR-G5.

T_{delay}, $T_{1/2}$, T_{sw}, and T_m are used as inputs to crediting recovering in CBDMT decisions trees and the HCR/ORE correlation.

For fire HRA, T_{sw} is based on the defined accident sequence modeled in the FPRA. For risk significant actions, this time is based on realistic generic thermal hydraulic analysis or simulation from similar plants in order to meet ASME 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 maybe cases where 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 Tdelay.

The output of NUREG 6850 Task 8 and Task 11 could provide a fire timeline that describes the (1) nature of the fire (fast or slow) (2) fire detector response times and (3) air flows that can impact fire growth.

T_{delay} represents the time at which the cue is received. When the cue is received 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 due to 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,

$$T_{delay} = T_{delay\ base\ case} + 30\ \text{min}$$

$T_{1/2}$ is best obtained by simulator observations. For scenarios where no instrumentation is impacted by fire, the $T_{1/2}$ time would be very similar to internal events time, since the EOPs are symptom based not initiator based and it is expected the operators will trust their instrumentation unless there is a compelling reason not to. For cases where the cues are partially impacted by the fire, the diagnosis many not be clearly identified in the procedures and these are the cases for which simulator observation would be the most beneficial.

For fire response actions, the diagnosis will typically be in the control room and the execution will be local and thus it is still possible to observe a $T_{1/2}$ time from simulator observations. If there is a need to model local cognition, then$T_{1/2}$ can be obtained by talk through and walk thoughts.

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 the operators will not travel directly thru a fire location. However, operators can travel through a smoky area to reach the local action. The travel time could be significantly impacted due to the fire location. As an initial estimate for existing internal events HFEs, it is recommended to increase T_M by at least 10 minutes, and if the HFE is risk significant this time should be verified.
- **Time to don SCBA and additional time SCBA would take to perform the actions**. The time to don SCBA can be observed during annual SCBA training, however, in training the 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 to time to don gear is used.

- **The presence of smoke could also impact the performance time**. If the operators cannot clearly see the valve they need to open then there may be additional time involved in locating the correct valve thus increasing T_m.

In some cases the fire procedures will specifically state that the local actions must be required with in a specified time and 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 through and talk through with operators.

NUREG-1792 and NUREG/CR-6850 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 which could be impacted by fire. The discussions of the bullets below are only considering the PSFs and how they related to time. Discussion of how each of the PFSs is addressed in the EPRI approach is shown in other parts of this section.

- **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, then 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 will typically be activated within 2 hrs of the start of the fire and can be credited for actions that occur later (after 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** – The manipulation time accounts for time it would take for the operators to interact with the plant, i.e. open valve or start pump. $T_{1/2}$ also accounts for time it would take for the operators to interpret or locate cues. For example, if the operators have to go the back of the control room to read an indication then the $T_{1/2}$ would be longer than if the indicators are located on the front computer panel.

- **Complexity of action involved** – $T_{1/2}$ accounts for complexity in diagnosis, as the more complex the diagnosis the longer it will take to make a correct diagnosis. T_m accounts for 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 as 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 diagnosis the need for the action. This could also impact T_{delay}, as 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 will not refer to the fire procedures immediately following the reactor trip but instead enter EOPs, then 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 and if the cue is a procedure step then T_{delay} must account for the total time to perform all previous steps in the sequence. If the procedures are ambiguously worded then it would take the operators longer to make the diagnosis and this is reflected in $T_{1/2}$. The manipulation time must account for the total time it takes to perform all the procedure steps. There could be several proceduralized steps that are not required for success but the operators will still perform these actions and this will lead to longer time to reach the final steps in the procedure.
- **Environmental Conditions –** Environmental conditions may slow the operator's response time and 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 then Shift Change can be credited.
2. If Tsw >= 360 minutes then Shift Change can be credited.
3. If Tsw >= 60 minutes then ERF Review can be credited.
4. If Tsw >= 15 minutes then STA Review can be credited.
5. The self review and extra crew are not time based recoveries.

NUREG/CR-6850 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 the following PWR scenario is given: The cue is an annunciators 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 the fire does not impact instrumentation. Operator interviews were done and the operators stated they anticipate the following sequence of events: trip the reactor, enter E-0 and disperse the fire brigade. After they ensure they have a transient and the plant is stable (No SI, no station blackout) then, they start reviewing annunciators. This scenario was observed in the simulator to determine the some of the timing. In this scenario, Tsw = 30 minutes by definition of the fire sequence, T_{delay} = 0 since the loss of suction occurs at the start of the fire and the annunciators is received at the start of the fire. $T_{1/2}$ was observed to be 5 minutes and this time accounts for the operators not acknowledging the annunciators within the first 4 minutes because they are busy dispersing the fire brigade and working in E-0. Once the operators do acknowledge the alarm they immediately send an operators to locally open the valve. A walk down was performed and it took 5 minutes to reach the valve location with no fire impacts. (For this case assume the fire has no impact on travel time). A time for opening the valve can not be measured due to plant operations but during outages this valve is regularly opened and the operators estimate that is takes 2-5 minutes to open the valve. (approximately 30 turns). In this case, T_m = 5minutes for travel time and 5 minutes to open the valve thus the total T_m is 10 minutes.

The following scenario would be input into the HRA methodology as shown below.

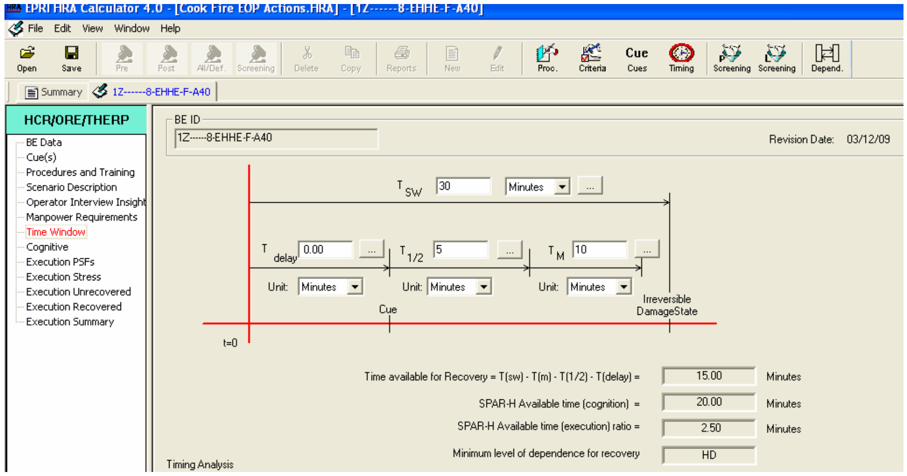


Figure C-36
Modeling for timing scenario 1

This timing information is used directly in HCR/ORE and the results are shown below. This action is a CP2 and average sigma is used because this is an EOP action and it is expected that the crew variation will be limited as the scenario models a well trained proceduralized path with no impact on instrumentation. For a sensitivity case the upper bound can be used.

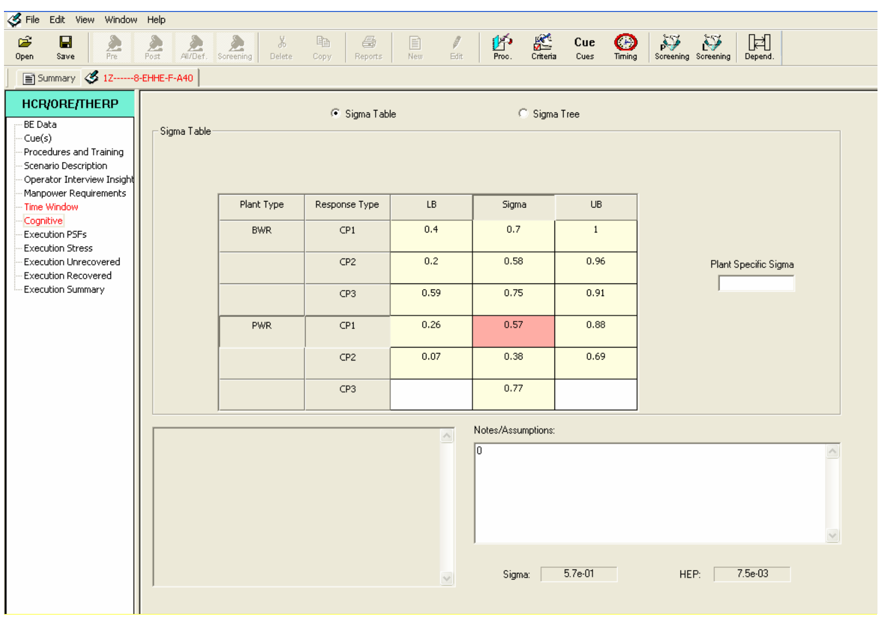


Figure C-37
Modeling of HCR/ORE for scenario 1

Within the CBDT no recoveries are applied for cognition since only one operator is performing the annunciator panel review for this scenario, assume there is no formal process for annunciator panel review and thus self review is not credited.

Scenario – 2: Use of less familiar or otherwise different procedure steps and sequencing could change the anticipated timing of actions in response to a fire. This timing effect is best illustrated by creating a variation of Scenario 1. In Scenario 1, it was given that the cue for the HFE was a control room annunciator. For Scenario 2, the same scenario applies with the exception that the cue for the action is given in the fire procedures and there is no control room annunciator for the spurious valve closure. The operator interviews revealed that the STA is responsible for oversight of the fire procedures and that operators will not open the fire procedures unless directed by the STA. (This is a fictitious scenario for illustrative purposes). T_{sw} and T_m, are the same between scenarios 1 and 2. For scenario 2, Tdelay would account for the time it takes for the STA to arrive at the control room and open the fire procedures. The valve still closes at T=0 however, in Scenario 1, an annunciator was lit at T=0 even though it is expected that the crew will not acknowledge the alarm. In Scenario 2 the only cue is a warning in the fire procedures and now Tdelay accounts for the time it takes to get to the step in the fire procedure. It is generally plant policy for the STA to be in the control room within 15 minutes of an event and this can be used to estimate Tdelay at 15 minutes. For Scenario 2, assume that the fire procedure provides a list of 15 valves that could spuriously close in the event of the a fire. There is a warning in the procedure that states if any of these valves spuriously close then locally open them. In this case the operators must check all the valves and determine which valves is closed and this would be modeled as a relatively long T1/2 time on the order of 7 minutes. For estimation, assume 30 seconds per valve position and if a better estimate is required then this process could be observed in the simulator.

The following shows the Scenario 2 is implemented in the HRA methodology

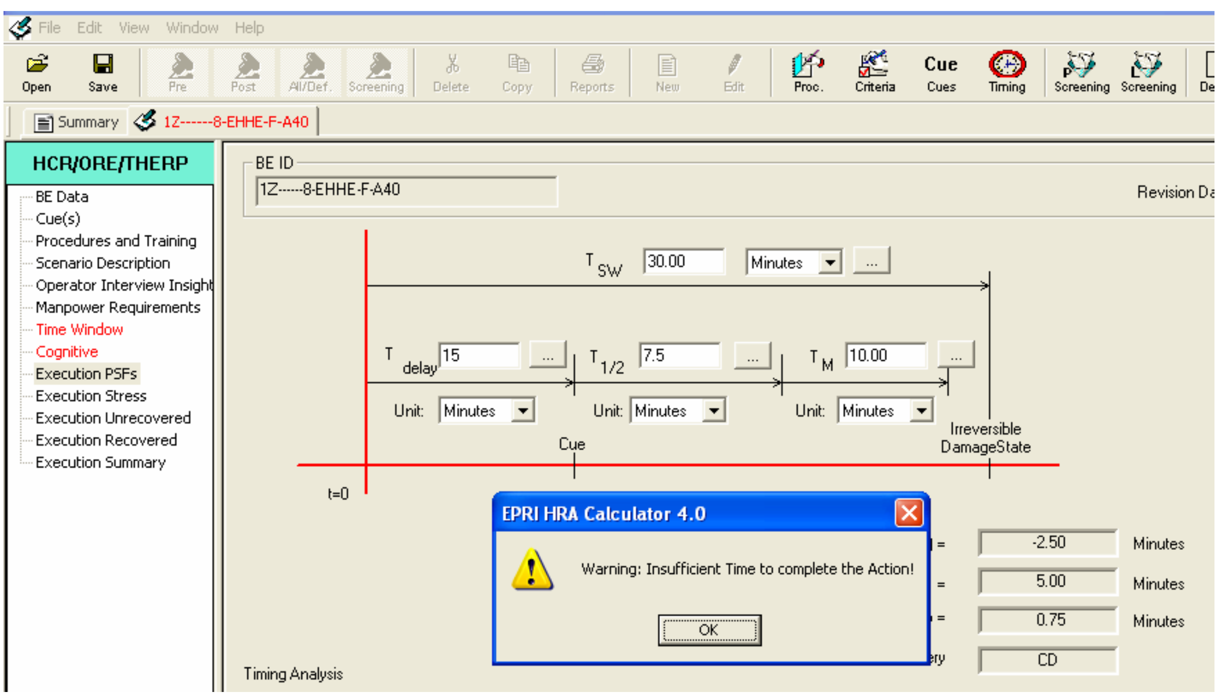


Figure C-38
Timing for Scenario 2- not enough time to complete the action

The HRA methodology provides a warning that there is insufficient time to complete the action and the HEP should evaluate to 1.0. These times could be revised if during operator interviews the operators stated that following diagnosis of a fire they would directly enter the fire procedures.

Scenario – 3: 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 but at other plants the fire brigade is a separate independent team.

For illustrative purposes, assume that that upon diagnoses of a fire a local 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. The additional time to locate a secondary person would be modeled in increase in T_m.

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 considering abandoning. If the scenario involves smoke in the control room then 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. It would be difficult to perform a demonstration of this in the simulator and thus 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 ARP and is trained on annually. Depending on the plant, there may be JPMs available to obtain an estimate of the manipulation time. However, training and JPMs are not necessarily performed using SCBA gear or addressing local fire effect 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 when the operators abandon the control room, the upper bound for sigma will always in the HCR/ORE correlation.

C.7.3 Procedures and Training

Procedures guidance is identified and documented in the procedure field in the HRA methodology. Procedures are considered explicitly in decision tree p_ca, p_cd, p_ce, p_cf, p_cg and p_ch and to model EOMs for execution. They are implicitly in used in quantification to identify the cues for cognition, critical task for execution, and to develop the timeline.

As stated in NUREG-1852 there are three roles of plant procedures which 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 of what needs to be done, and unless it can be argued to be “skill-of-the-craft,” they should also contain guidance for how and where it should be done, and what tools or equipment should be used.

These roles are addressed within the HRA methodology as follows:

1. 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 diagnosis the action.
2. 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.
3. Decision tree p_ca, addresses procedure usage to assist the operator if the instrumentation is unreliable. The fire may cause the instrumentation to be unreliability because it is either failed by the fire or providing spurious readings. For cases where 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 address if 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 and this is modeled in decision tree p_cb. 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.

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 procedure branch is used. .In cases where the fire procedures are implemented prior the EOPs the workload could still be considered high if there are multiple fire procedures or multiple attachments be used at the same time.

In some cases, especially for some ex-CR actions, procedures might not exist or be readily retrievable, or ambiguous in some situations. 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 a critical factor.

For cases where 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 where the procedure is ambiguously worded the down 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 following example.

Table C-17
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 above it is not clear why the same equipment appears in both the affected column as well as the available column and the Ambiguously worded procedure branch would be applied.

Like procedures, training for both control room and local actions, is an important factor in assessing operator performance. As stated in NUREG- 1852, training serves three supporting functions for operator performance during a fire:

1. Training establishes familiarity with the Fire procedures and equipment needed to perform the desired actions, as well as, potential conditions in an actual event,
2. 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, and
3. Training gives personnel the opportunity to practice their response without exposure to adverse conditions, thereby 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 (for example the types of scenarios, frequency of training or classroom discussions and frequency of simulations) for addressing the range of possible fires 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 usage 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 tree 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 would include addressing fire effects. In all the decision trees training is considered as 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 is identified and documented in the training fields within the HRA methodology. Training is considered explicitly in decision tree p_ca, p_cd, p_cf and p_cg.

C.7.4 Complexity

As stated in NUREG-1792 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 vs. 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 multivariable or single-variable associated task, whether special sequencing or coordination is required in order for the action to be successful (especially if it involves multiple persons in different locations), whether the activity may require very 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 make an assessment of the complexity of the action as simple or complex, both for cognition and execution in order to meet ASME standard requirement HR-G3 Category I. For quantification the EPRI approach addresses the following issues which together define complexity.

Cognition complexity

There are very few EOP actions that would require complex diagnosis since 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 and thus make 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 then it will take the operators longer to make the correct diagnosis and this is reflected in the $T_{1/2}$ value. Procedure usage for fire response is considered complex if the operators must interpret the instructions due to unclear wording. Ambiguous wording is modeled in decision tree p_cf. Additionally, the usage of the fire procedures is not always straight forward which would lead to an increase in T_m. Sometime the usage of the procedure is left at the discretion of the operators and in this case the diagnosis would be complex. If the usage of the fire procedures is left to the discretion of the operators then there will be a greater variation among crew and the upper bound for sigma is used in the HCR/ORE.

For cognitively complex actions additional crew may be credited in the CBDT decision trees as it 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 provided that there is enough time available.

Execution complexity

- **Single vs. 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 task required the longer it will take to perform the actions and this impacts T_m. Using THERP each critical task is assigned failure probability and 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 between team members to successfully complete the action, then higher the complexity. If the action involves oral instructions among crew members then THERP table 20-8 is used for selecting and EOM. If a crew member must report back other members after completing a task an additional critical task of reporting back is included and is 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 between the staff members is required. Generally, if multiple locations must be visited to complete the action, then 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 EOC and EOMs that can results in a high failure probability.
- **Multiple functions** – Multiple functions may need to be performed in the execution of an action (e.g., both align 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 value would be selected from THEPR 20-11. If both opening and monitoring are required then 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 in performing the action. To the extent 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 and if any single PSF is present the stress level is set to high. If two or more of these PSFs are identified then an additional factor of 2 is applied to P_{exe}. Additionally, accessibility will impact the manipulation time and it is always ensured that there is enough time to complete this action.

C.7.5 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 has to 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 [e.g., see Swain and Guttmann [3] for a more detailed definition and discussion of stress and workload]. To the extent crews or individuals expect to be under high workload, time pressure, and stress, it 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 working in both the EOPs and the fire procedures at the same time then 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 equal or exceed 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 if the operators expect to feel time pressure due to a fire.

Stress is addressed in the EPRI approach using a simplified decision tree shown below.

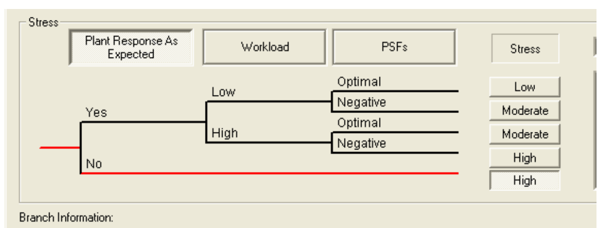


Figure C-39
Stress decision tree

Within the EPRI approach stress quantitatively only impacts execution. For diagnosis, PSFs that make up stress such as workload, training, procedures and cues and indications are considered explicitly and described above. The stress level determined in the stress decision tree is reflected as a direct multiplier to the execution using the values shown below.

Table C-18
Stress PSF Values

HRA Methodology Stress Level	Multiplier to P_{exe}
Low	1
Moderate	2
High	5

The first branch of the decision addresses if the operators believe the plant is responding as expected. For fire scenarios that involve a transient with no instrumentation impacts then the plant would be responding as expected. The spuriously actuation of equipment is not expected and if the fire scenario involves spurious actuation then the no branch would be used. Another example would be if the operators lose control from the control room due to fire impacts and MCR abandonment is required.

If any one of the following PSFs are considered poor due to the fire the PSFs branch of the stress decision tree is considered negative.

- Poor lighting
- Heat or smoke due the effects of the fire. It is assumed that the HRA analyst has assessed qualitatively that even though there is smoke present the action can still be completed.
- Radiation levels are above background
- Respirator/SCBA required
- Special tools or clothing are required.
- Radio communication required.
- Accessibility is limited.

If any two of the above PSFs are considered poor then the high stress is applied **and** P_{exe} is multiplied by an additional factor of 2. For example, if the local action requires the operators to travel thru a smoke filled area and a respirator is required then the additional factor of two would be applied. All of the above impacts are also considered in development of the timeline. If there is not enough time to complete the actions due to anyone of the PSFs above then the HEP should evaluate to 1.0.

C.7.6 Human Machine Interface

Human Machine Interfaces (HMI) impact operator performance differently depending on the location of the action. In general, NUREG-6580, NUREG-1852 and NUREG- 1792 all agree that for control room actions, the HMI will have minimal or positive affect on the human performance. This is because problematic HMIs have either been taken care of by control room design reviews and improvements or they are easily worked around by the operating crew due to the daily familiarity of the control room boards and layout. However, any known very poor HMI should be considered as a negative influence for an applicable action even in the control room. For control room actions for fire HRA, the human machine interfaces will remain similar to internal events with the exception of potential impacts on instrumentation.

CBDT addresses HMI issues in decision trees p_ca, p_cb and p_cc. 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 effected by the fire. (See the discussion on cues above).

For actions that require local diagnosis decision tree p_cc could be important as the local indications may not be easy to locate and once located they could also 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 execution of control room actions, the HMI is considered negligible and 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 which are not typically modeled in internal events. The valves may not be manipulated as often and thus not all the HMI issues have been addressed. Unclearly or ambiguously labeled, 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 all 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 unclear or ambiguously labeled valves.

C.7.7 Environment

Within the HRA methodology, environmental impacts are considered within 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 success of operator actions since they rarely change control room habitability. However, if the fire directly affects the MCR either 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. If any smoke or toxic gas is present in the control room then the stress decision tree evaluates to high stress because the plant is not responding as expected (since the HVAC system is failed) and an additional factor 2 is applied to P_{exe}. It is outside the scope of the EPRI approach to address different levels of smoke If smoke in the control room impacts the 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 the operator performance. Radiation, lighting, temperature, humidity, noise level, smoke, toxic gas, even weather for outside activities (e.g., having to go on a potential 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 the operator actions in the locations where the actions are to be taken and along access routes. If any one of the above PSFs are considered to have a negative impact then high stress is applied. If any two of the above PSFs are considered poor then the high stress is applied and P_{exe} is multiplied by an additional factor of 2. In most of the cases described above there is more than one negative PSF (since the PSFs are not independent) and therefore the additional multiplier of 2 will always be applied.

During a fire, there is the potential that the crews ideal travel path to the action location will be blocked by the fire and will lead to a delay or inability to reach the action location. Where alternate routes are possible, the demands associated with identifying such routes and any extra time associated with using the alternate routes should be factored into the analysis. Per NUREG/CR-6850, 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 due to the fire location then the time for the detours is to be included in T_m. Additionally the stress would be considered high since the accessibility for the action is limited by the fire location.

An evaluation should be done addressing the issue that any equipment that is necessary for the completion of hot shutdown from the remote shut down panel is accessible and in working order such that it will not be adversely affected by the fire or its effects (for example, 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 put upon the operators working in the likely unfamiliar environment and ex-CR controls. If it is qualitatively assessed that at the hotshot down panel a piece of equipment would not be in working order and this equipment is required for success then 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.

C.7.8 Special Equipment

Due to varying environmental conditions during a fire, the crew may require the use of special equipment. These items, identified in NUREG-1852 as portable equipment can include: keys, ladders, hoses, flash lights, clothing to enter high radiation areas and for fire special protective clothing and breathing gear. The accessibility of these tools needs to be checked to ensure they can be located and accessible during a fire. If they can not be accessed during the fire then 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 familiarly with special equipment can be addressed by choices for EOCs in THERP.

The call for abandoning the MCR might also call upon the need to don protective gear or self contained breathing apparatus (SCBA). 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 to time to don gear is assumed. It is assumed that operators would not need SCBA gear to make diagnosis, and therefore SCBA gear would only impact execution. 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. If SCBA gear is required in most cases there will be more than one negative PSF and thus the stress level will be considered high and an additional factor of 2 is applied to P_{exe}.

Any additional special equipment needs are collectively addressed by applying high stress and applying an additional factor for 2. (See discussion on stress).

C.7.9 Special Fitness Needs

According to NUREG/CR-6850, the fire and its effects could cause the need to consider actions not previously considered under internal events, or changes to how previously considered actions are performed, checks should be made to ensure unique fitness needs are not introduced. Unique fitness needs could include:

- Having to climb up or over equipment to reach a device. This could be to the fire blocking the ideal travel path.
- Needing to move and connect hoses, using an especially heavy or awkward tool.
- Physical demands of using respirators. This could impact communication as well.

If the fire cause any of the above unique fitness needs such that not all crew members could perform the required tasks then 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 due to accessibility. Communication impacts would be reflected in an increased stress level.

C.7.10 Crew Communications, Staffing and Dynamics

Crew to crew variability modeled is the HCR/ORE by using the appropriate bound for sigma. For EOP actions where there are no instrumentation impacts the average case is used. For cases where there could be crew to crew variability due to 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 provided there is enough time available. The HRA methodology documents the total number of people required for success and if the total number of crew required is greater than the total number available then the HEP should be set to 1.0.

Team crew dynamic

Team/crew dynamics and crew characteristics are essential to understanding 1) how and where the early responses to an event occur and 2) 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 the crews that can affect overall crew performance. NUREG-1792 recommends a review of team dynamics include the following:

- Are independent actions encouraged or discouraged among crew members (allowing independent actions may shorten response time but could cause inappropriate actions going unnoticed until much later in the scenario)? If this scenario is identified to be modeled this would 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 analysts wishes to model the recovery by a secondary person, this would be modeled by assuming the first person failed the action and the second member would receive a recovery cue to either check that the previous task was completed or to 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 the main document could be used to assessed the dependency between the actions.
- Are there common biases or "informal rules?" For example, is there a reluctance to do 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 procedural steps are interpreted. Operator trust of the procedures are 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 annunciators 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, T1/2 and Tdelay would reflective of the time at which the operators leave the EOPs and acknowledge then annunciator. Additional, if the interviews confirm that all operators will be following a specific cue then extra crew can be credited as a recovery in the CBDT.
- 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? This is addressed decision tree p_cb and proceduralized checks are modeled as recoveries for execution. The following example of a proceduralized recovery is shown below:

For fire HRA, the typical internal events crew dynamics may change as a result of responding to a fire and need to be re-considered. 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 availed exceeds total number of crew required then 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 not applying recoveries for cognition. Such differences may be best determined by talk-through with operations staff, as well as observing simulated responses of fire scenarios.

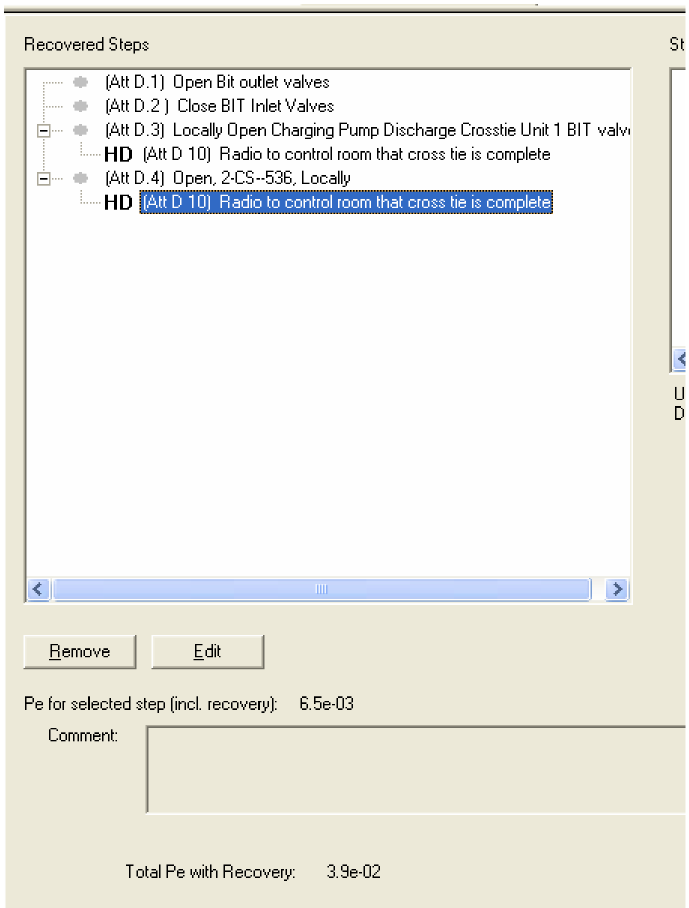


Figure C-40
Crediting proceduralized recovery within P_{exe}

For MCR abandonment actions or alternate shutdown actions, the crew will be dispersed to various alternative shutdown panels and controls and this requires additional coordination among all crew members. It must be assured that there are adequate control room members necessary to fulfill the needs of proper shutdown actions from alternative and remote shutdown panels if not then the HEP =1.0.

Communication

For both internal events and fire HRA control room actions, communications among crew should be verified. Typically there will be an established strategy for communicating in 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 problematic; however, any potential problems in this area (such as having to talk with special air packs and masks on in the control room in a minor fire) should be accounted for if they exist. Communications and its impact on cognition is modeled in decision tree p_cc and additional crew can be credited for recovery in the CBDT trees provided there is enough time available.

If SCBA is required to be worn, this apparatus might interfere with clarity in communications between the team. Execution while wearing SCBA gear is reflected as an increase in stress level. If communication is required for successful execution while wearing SCBA gear then the stress level considered to be high and P_{exe} is multiplied by an additional factor of 2.

The general EPRI approach for communication is to verifies that is possible and if it not possible and required for success then the HEP =1.0.

C.8 Example of Fire HFE quantified using the EPRI HRA Methodology

This section provides an example HFEs modeled using the EPRI approach and the HRA methodology. This example is for an existing EOP action that is required for the fire HRA. In the fire scenario the position switch is failed by the fire so the control room operators can not open the valve from the control room and must dispatch a local operator to perform this action. The indication that the value is failed provides a correct reading and is not considered to impact the diagnosis. The fire procedures also direct the operator to locally open the valve.

Scenario-1, Locally open 8804 A/B for high pressure recirculation following a spurious PORV LOCA

Basic Event Summary

Table C-19
Scenario-1 summary

Analysis Method	CBDTM/HCR Combination (Sum)
P(cog)	3.4e-03
P(exe)	2.5e-03
Total HEP	5.9e-03
Error Factor	5

Assigned Basic Events
None

Related Human Interactions
Switchover to Recirc 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 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 and the operators tend to look at both the position switch and the monitor light boxes.

The cue for starting cold leg recirc is RSWT level <33%

Degree of Clarity of Cues & Indications
Very Good

Procedures
Cognitive: ES 1.3 (Transfer to Cold Leg Recirculation) Revision: 26
Execution: ES 1.3 (Transfer to Cold Leg Recirculation) Revision: 26
Other: CP-M-10 () Revision: 21A

Cognitive Procedure
Step: 8.g.
Instruction: Check for charging pps amps, Charging injection flow and SI Pp flow if pps are in operation

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

The procedure step in CP-M-10reads
Manually close 8804A Power will be isolated (by opening 480V MCC feeder breaker 52-1G-58 to preclude spurious operation of 8982A. If 8982A has opened, then locally close valve 8980 after opening its power breaker 52-1F-31

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

Training
Classroom, Frequency: 0.5 per year
Simulator, Frequency: 0.5 per year

JPM Procedure
Not Selected

Identification and Definition

1. Initial Conditions: Steady State, Full power
2. Initiating Events:
   Fire in Area 5A2
   PORV spuriously opens resulting in small LOCA

   The fire starts in TRY12 (transformer) and impacts targets in the plume and vertical trays adjacent to the flames.
3. Accident sequence (preceding functional failures and successes):
   Reactor trip
   Turbine trip
   No containment spray required
   AFW successful
   SSPS not impacted
   SI actuates due to open PORV
   Cooldown and depressurization required.
   Switch over to recirc required.
   8804A failed to open from CR due to fire damage.
4. Preceding operator error or success in sequence:
   Operator fail to detect spurious PORV opening prior to auto SI actuation.
   Operators controlled ECCS flow to match make-up flow with leakage rate
   RHR pumps tripped
   Cooldown and depressurization either failed or failed to be completed before RSWT reaches 33%

   Procedure path:
   E-0 (Step 9b RNO transfer)
   E-1 (Step 12 Check RCS Pressure - GREATER THAN 300 PSIG)
   E-1.2 (RSWT level <33% Fold out page)
   E-1.3 (Step 8 - Place 8804 A RHR Hx No. 1 to Chg Pp Suction
5. Operator action success criterion:
   Locally open 8804A and B located at 73’ RHR Access or 100’ GE - 8804A failed to open from CR due to fire damage.
6. Consequence of failure: RWST depleted - Core damage
7. Equipment Affected By Fire:
   Spuriously open of EP-1-52 HG15-DC (startup supply breaker to vital buses)
   EDG 1-2 failed
   RHR 1-1 failed
   CCP 1-2 failed
   Other Bus G equipment failed.
   PORV-455 C spuriously opens
   Block valve 8000B failed

8. Notes:
   This is an internal events action but not currently modeled in PRA. It will be added to FPRA model.

   The current screening HEP for this action is 0.1

Key Assumptions

Operator Interview Insights

The operators stated that it would be obviously that 8804A or B failed to close when attempted from the control room. In the control room in addition to the position switches the valve position are also monitored on monitor light boxes. The cabling for the monitor light boxes are separate from the valve cabling.

The operators estimate that it will take 10 minutes to crank open valve and 15 minutes to travel to the valve location.

The operators are aware that switch over to recirc is coming and they will have an operators preview E 1.3 (step 13 of E-1 PREVIEW EOP E-1.3, TRANSFER TO COLD LEG RECIRCULATION.) During the preview they anticipate that the preview will alter the operators to a failed valve.

Manpower Requirements

Crew Member	Included	Total Available	Required for Execution	Notes
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		

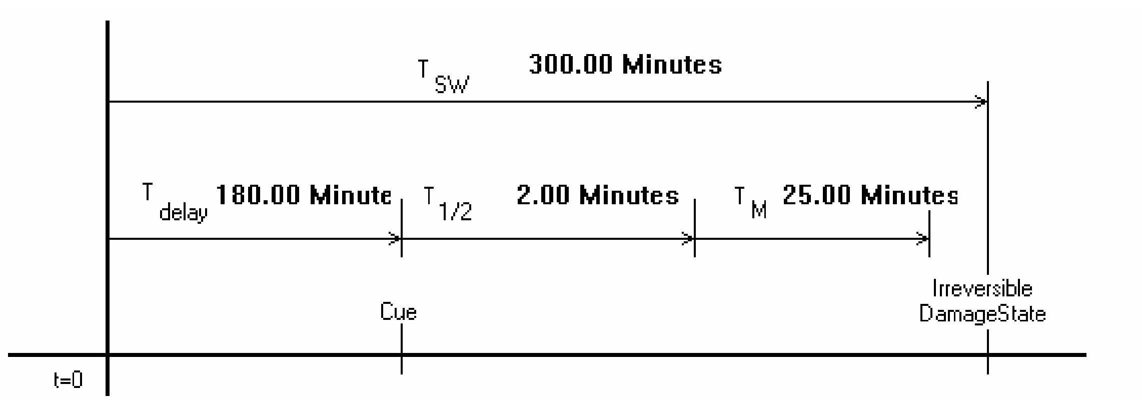
Execution Performance Shaping Factors

Environment	Lighting	Normal
	Heat/Humidity	Normal
	Radiation	Background
	Atmosphere	Normal
Special Requirements		
Complexity of Response	Cognitive	Complex
	Execution	Simple
Equipment Accessibility	Control Room	Accessible
	73' RHR ACCESS	Accessible
Stress	High	
	Plant Response As Expected:	No
	Workload:	N/A
	Performance Shaping Factors:	N/A

Performance Shaping Factor Notes

Due to the fire and the spuriously opening of valves the plant is not responding as expected.
The fire location does not impact the operators from reaching 73' RHR ACCESS
Stress is considered High.

Timing



Timing Analysis: Tsw - 300 min. Time to RWST depleted
Tdelay =120 switchover to recirc. RWST <33%
T1/2 = 2 minutes Estimated time attempt to close CR switch and relies that valve must be closed locally.
Tm = 25 minutes from operator interviews

Time available for recovery: 93.00 Minutes

SPAR-H Available time (cognitive): 95.00 Minutes

SPAR-H Available time (execution) ratio: 4.72

Minimum level of dependence for recovery: ZD

Cognitive Unrecovered CBDTM

Scenario-1

Table C-20
Scenario-1 cognitive unrecovered

Pc Failure Mechanism	Branch	HEP
Pc_a: Availability of Information	a	neg.
Pc_b: Failure of Attention	i	neg.
Pc_c: Misread/miscommunicate data	a	neg.
Pc_d: Information misleading	a	neg.
Pc_e: Skip a step in procedure	c	3.0e-03
Pc_f: Misinterpret instruction	b	3.0e-03
Pc_g: Misinterpret decision logic	j	1.0e-03
Pc_h: Deliberate violation	a	neg.
Sum of Pc_a through Pc_h = Initial Pc =		7.0e-03

Pc_a Notes
The monitor light boxes in the control room are unaffected by the fire.

Pc_b Notes
2 hrs into the scenario the workload is still considered high because the operators will be working in both the fire procedure and the EOPs. The operators are only required to check the monitor light boxes located on the front panels of the control room for the valve positions.

Pc_c Notes
The checking of the monitor light boxes does not require the use of formal communication to complete. However complete of step ES 1.3 does require formal communication.

Pc_f Notes
All the available information would not be available since the position indicator lights may have failed due to fire. All steps of EOPs are well trained on.

Pc_g Notes
A valve failing due to fire is not trained on.

Cognitive Recovery CBDTM

Scenario-1

Table C-21
Scenario-1 cognitive recovery

	Initial HEP	Self-Review	Extra Crew	STA Review	Shift Change	ERF Review	DF	Multiply HEP By	Override Value	Final Value
Pc_a:	neg.	-	-	-	-	-	-	1.0e+00		
Pc_b:	neg.	X	-	-	-	-	-	1.0e-01		
Pc_c:	neg.	-	-	-	-	-	-	1.0e+00		
Pc_d:	neg.	-	-	-	-	-	-	1.0e+00		
Pc_e:	3.0e-03	-	-	-	-	-	-	1.0e+00		3.0e-03
Pc_f:	3.0e-03	-	-	X	-	-	-	1.0e-01		3.0e-04
Pc_g:	1.0e-03	-	-	X	-	-	-	1.0e-01		1.0e-04
Pc_h:	neg.	-	-	-	-	-	-	1.0e+00		
Sum of Pc_a through Pc_h = Initial Pc =										3.4e-03

Notes
Due to time available STA is credited for recovery.

Cognitive HCR/ORE

Scenario-1

Table C-22
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 since this action is both 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

Table C-23
Scenario-1 execution unrecovered

Procedure: ES 1.3, Transfer to Cold Leg Recirculation		Comment				Stress Factor	Over Ride
Step No.	Instruction/Comment	Error Type	THERP		HEP		
			Table	Item			
E-1.3 G RNO	Locally open 8804 A (73’ 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 8g	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

Execution Recovery

Scenario-1

Table C-24
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 G RNO		Locally open 8804 A (73’ RHR ACCESS)	2.8e-02				2.5e-03
	E-1.3 Step 8g	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**

C.9 References

1. Software Users Manual, *The Human Reliability Calculator Version 4.0.* EPRI, Palo Alto, CA, and Scientech, Tukwila*, WA*. January 2008. Product ID. 1015358.
2. *An Approach to the Analysis of Operator Actions in Probabilistic Risk Assessmen.* Electric Power Research Institute, 1992. EPRI TR-100259.
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4. NUREG/CR-1278, "Handbook of Human Reliability Analysis With Emphasis on Nuclear Power Plant Applications", A.D. Swain and H.E. Guttman, 1983.
5. *SHARP1 – A Revised Systematic Human Action Reliability Procedure.* 1990. EPRI NP-7183-SL SHARP/SHARP1.
6. *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities.* September 2005. NUREG/CR-6850/EPRI 1011989.
7. ASME RA-S-2000, "Standard for PRA for Nuclear Power Plant Applications", Rev 14A, May 11, 2001 supplemented by ASME RA-Sa-2003, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 5, 2003, supplemented by ASME RA-Sb-2005, "Addenda to Standard For Probabilistic Risk Assessment For Nuclear Power Plant Applications", December 2005, all by American Society of Mechanical Engineers.
8. NUREG-1792, "Good Practices for Implementing Human Reliability Analysis (HRA)," Sandia National Laboratories, 2005.
9. NUREG-1852, "Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire", October 2007.

D
DETAILED QUANTIFICATION OF POST-FIRE HUMAN FAILURE EVENTS USING ATHEANA

D.1 Objective

The goal of this appendix is to provide an overview of describe the process of applying A Technique for Human Event Analysis (ATHEANA) used 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]. ATHEANA is a human reliability analysis (HRA) methodology designed to support the understanding and quantification of HFEs in nuclear power plants. This approach may be used in those instances in which a simpler HRA methodology is not valid due to the complexity of the scenario. Based on reviews of operating experience in technically challenging domains such as nuclear power plants, a key observation that drives the ATHEANA approach is that HFEs that contribute to equipment damage or other severe consequences, and that involve highly trained staff using considerable procedure guidance, 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 where their training and procedures are inadequate or do not apply or when some other unusual set of circumstances occur. 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 these characteristics and 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.

D.2 Summary of Method

Step-by-step guidance for 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 much more than simply a quantification process and it entails several steps prior to quantifying HEPs. These steps are presented in Figure D-1. Detailed discussion of each of these steps can be found in NUREG-1880 [1]. While it is recommended that analysts review the introduction to the ATHEANA User's Guide 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 identified in applying steps 1 - 3 (Sections 3 – 5) of this report. However, it will still be useful to review ATHEANA steps 1-5, particularly step 5, given the fire context, before proceeding. It may not be necessary to perform Step 6, the deviation analysis, since the fire scenarios can be looked at as deviation scenarios[1] themselves. However, to the extent 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, significant staffing shortage for particular scenario) then explicit modeling of such factors may be useful. Steps 5, 6, and 9 of the ATHEANA process provide guidance for identifying, modeling, and quantifying such factors. Steps 7-9, which includes the quantification process, will usually need to be applied (see discussion below).

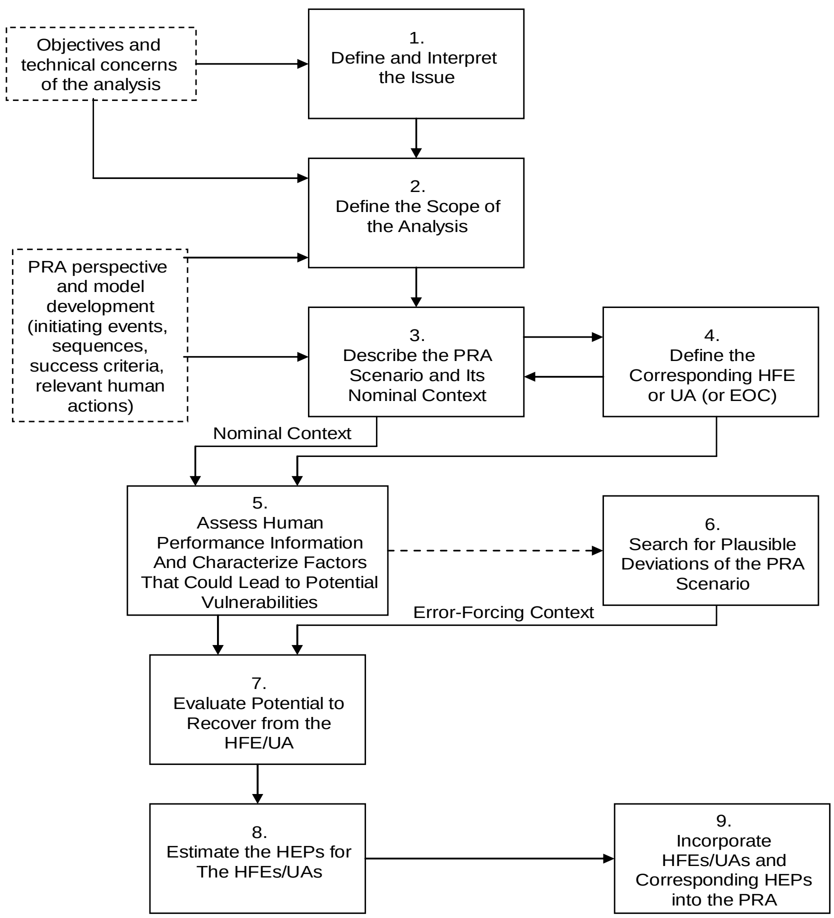

Figure D-1
Steps in the ATHEANA methodology

If the ATHEANA method is selected for use, the quantification step is to be performed as usual. However, the analyst must consider that the fire context creates a number of factors that influence crew performance and these factors must be accounted for within the ATHEANA analysis. This information will be provided by following the guidance in the body of this report

[1] 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.

and may be supplemented by following the ATHEANA steps. 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. 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.

D.3 Application of Method

Although the early steps (steps 1-4 and step 5 to some extent) within the ATHEANA methodology will most likely be completed through the progression through sections 3-5 of this document, it is recommended that the analyst address the search for vulnerabilities described in Step 5 of ATHEANA to make sure 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 ATHEANA User's Guide section 3.5.2.3), then section 3.6.2.2 of the User's Guide should also be reviewed. This section provides guidance for determining whether deviation scenarios, such as those with potentially important aleatory influences, should be carried forward to the quantification process. It will also be necessary to apply the final qualitative step (step 7) within ATHEANA before continuing forward with quantification. In step 7, the analyst examines the recovery potential for the HFE being analyzed in the context of each scenario documented. Upon the completion of this step, the description of each scenario is extended using the information obtained in the evaluations, in order 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. The approach for quantification in ATHEANA relies on a very structured, facilitator led, expert opinion elicitation where experts provide their review and insights on the factors judged to be driving performance, along with their judgments as to the appropriate estimate for the HEP. In estimating each HEP, the experts consider the plant conditions and relevant PSFs associated with context in a holistic and integrated manner, and ultimately arrive at an estimate for each HEP. Guidance on forming the team of experts, controlling for biases when performing elicitations, addressing uncertainty, and other issues associated with eliciting probabilities is given in the ATHEANA User's Guide (NUREG-1880 [1]). A reminder that the team of experts should be expanded to include experts knowledgeable in important relevant factors within a fire context.

Fire-Specific Application of ATHEANA

This section provides some discussion of how to specifically apply ATHEANA HRA method when using this document.

As described in Section 6, an analyst may decide to perform detailed HRA analysis using ATHEANA for all HFEs modeled in the FPRA.2 Alternately, the analyst may be using ATHEANA because the scoping HRA method did not or could not provide the desired analysis results for some specific HFEs.

In both cases, it is expected that qualitative HRA analysis, such as that described in Section 5, has been performed. From such a qualitative analysis, it is expected that the analyst(s) will have developing a general understanding of possible operator performance in fire scenarios, for example, a general understanding of:

- procedures used in fire scenarios
- usage of procedures
- 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 errors of omission & errors of commission)

If not already developed in implementing Section 5, 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, and 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 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 use of specialized equipment
- timelines or other ways of representing the time sequencing of events (e.g., plant behavior, equipment & operator response) in fire scenarios

Then, for each HFE and associated fire scenario, qualitative HRA analysis using ATHEANA should address the following (with the help of and input from operator trainers and, as needed, other experts in operations, PRA, and thermal-hydraulics, for example):

- identification of any factors (e.g., specific fire scenario conditions, timing of plant conditions and behavior associated with scenario, availability of specific equipment – including equipment degradations) that may influence different operator decisions (identified above)

[2] However, the authors recommend the use, to the extent possible, of the scoping HRA method provided in this report. The scoping HRA method is consistent with the ATHEANA method since it is based, in part, on some of the underlying concepts and principles in ATHEANA. Also, because the number of influencing factors addressed by the scoping method is limited, it is expected to require fewer resources to apply. However, there are two instances in which the use of ATHEANA is recommended: a) important plant-specific or scenario-specific features cannot be addressed using the scoping HRA method, or b) the analyst thinks that a detailed HRA analysis would result in lower HEP value(s) than that assigned by the scoping HRA method.

- identification of any tradeoffs (i.e., operators have to make impromptu choices between alternatives, for which they may be both positive and negative effects) or other difficult decisions (see Table 9.15a in NUREG-1624, Rev.1 [2] for other examples of other potential problems in “response planning”) that operators may need to make
- identification of potential situations (or other reasons) why operator 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 [2] for examples of scenario characteristics that could lead to problems in “situation assessment” – spurious indications would fall under the category of “missing information”)
- 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 “error-forcing context”)

After the qualitative analysis described above has been performed, then HFE quantification using ATHEANA can be performed. (It should be noted that, in ATHEANA, there can be some iteration between quantitative and qualitative analysis in using ATHEANA. The only concern is that each HFE (and sub-event HFEs) and associated can be understood by all participants in the quantification process.

For HFE quantification, NUREG-1880 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), and
3. quantification of the failure probability for the HFE (or HFE sub-event) given #1 & #2.

Analysts have the choice of defining new HFEs (instead of HFE sub-events – called unsafe actions in NUREG-1880 [1] and NUREG-1624, Rev. 1 [2]), or summing the HFE sub-event probabilities.

D.4 References

1. NUREG-1880, “ATHEANA User’s Guide,” June 2007.
2. NUREG-1624 Rev 1, “Technical Basis for Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA),” May 2000.

E
DEFINITION OF TERMS

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) (ASME-RA-2002/RA-Sb-2005 [2]).

adversely affect: In the context of fire PRA, to impact, via fire, plant equipment items and cables leading to equipment or circuit failure (including spurious operation of devices).

cable: Referring solely to “electric cables,” a construction comprising one or more insulated electrical conductors (generally copper or aluminum). A cable may or may not have other physical features such as an outer protective jacket, a protective armor (e.g., spiral wound or braided), shield wraps, and/or an uninsulated ground conductor or drain wire. Cables are used to connect points in a common electrical circuit and may be used to transmit power, control signals, indications, or instrument signals.

cable failure mode: The behavior of an electrical cable upon fire-induced failure that may include intra-cable shorting, inter-cable shorting, and/or shorts between a conductor and an external ground. (Also see “hot short.”)

circuit failure mode: The manner in which a conductor fault is manifested in the circuit. Circuit failure modes include loss of motive power, loss of control, loss of or false indication, open circuit conditions (e.g., a blown fuse or open circuit protective device), and spurious operation.

concurrent hot short: The occurrence of two or more hot shorts such that the shorts overlap in time (e.g., a second hot short occurs before a prior hot short has self-mitigated or has been mitigated by an operator action).

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 (ASME-RA-2002/RA-Sb-2005 [2] and ANSI/ANS-58.212OO7 [1]).

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 (ASME-RA2002/RA-Sb-2005 [2]).

core damage frequency (CDF): Expected number of core damage events per unit of time (ASME-RA-2002/RA-Sb-2005 [2] and ANSI/ANS-58.21-2007 [1]).

damage criteria: Those characteristics of the fire-induced environmental effects that will be taken as indicative of the fire-induced failure of a damage target or set of damage targets.

damage threshold: The values corresponding to the damage criteria that will be taken as indicative of the onset of fire-induced failure of a damage target or set of damage targets.

damage target: See “target.”

distribution system: Piping, raceway, duct, or tubing that carries or conducts fluids, electricity, or signals from one point to another (ANSI/ANS-58.21-2007 [1]).

electrical overcurrent protective device: An active or passive device designed to prevent current flow from exceeding a predetermined level by breaking the circuit when the predetermined level is exceeded (e.g., fuse or circuit breaker).

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 (for example, 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 (ASME-RA-2002/RA-Sb-2005 [2] and ANSI/ANS-58.21-2007 [1]).

exposed structural steel: Structural steel elements that are not protected by a passive fire barrier feature (e.g., fire-retardant coating) with a minimum fire-resistance rating of 1 hour.

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 wild- fires) are considered external events (see also “internal event”). By convention, loss of off-site power not caused by another external event is considered to be an “internal event” (ANSI/ANS-58.2l-2007 [1]).

failure mechanism: Any of the processes that result in failure modes, including chemical, electrical, mechanical, physical, thermal, and human error (ASME-RA-2002/RA-Sb-2005 [2] and ANSI/ANS-58.21-2007 [1]).

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, leaks) (ASMERA-2002/RA-Sb-2005 [2] and ANSI/ANS-58.21- 2007 [1]). Special Note: In the context of fire PRA, “spurious operation” (see definition below) is also considered a failure mode above and beyond failures that “preclude successful operation.”

failure probability: The likelihood that an SSC will fail to operate upon demand or fail to operate for a specific mission time (ASME-RA2002/RA-Sb-2005 [2] and ANSI/ANS-58.21-2007 [1]).

fire analysis tool: As used in this standard, “fire analysis tool” is broadly defined as any method used to estimate or calculate one or more physical fire effects (for example, temperature, heat flux, time to failure of a damage target, rate of flame spread over a fuel package, heat release rate for a burning material, and smoke density) based on a predefined set of input parameter values as defined by the fire scenario being analyzed. Fire analysis tools include, but are not limited to, computerized compartment fire models, closed-form analytical formulations, empirical correlations such as those provided in a handbook, and lookup tables that relate input parameters to a predicted output.

fire area: A portion of a building or plant that is separated from other areas by rated fire barriers adequate for the fire hazard (RG 1.189 [4]). (Note that a rated fire barrier is a fire barrier with a fire-resistance rating.)

fire barrier: A continuous vertical or horizontal construction assembly designed and constructed to limit the spread of heat and fire and to restrict the movement of smoke (NFPA805 [5]).

fire compartment[1]: A subdivision of a building or plant that is a well-defined enclosed room, not necessarily bounded by rated fire barriers. Afire compartment generally falls within a fire 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 is a term 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 (Reference: This definition derived from NUREG/CR-6850, TR- 1011989 [6]). In this 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: That initiating event assigned to occur in the fire PRA plant response model for a given fire scenario (adapted from NUREG/CR-6850-EPRI TR1011989 [6]).

fire modeling: As used in this standard, “fire modeling” refers to the process of exercising a fire analysis tool including the specification and verification of input parameter values, performance of any required supporting calculations, actual application of the fire analysis tool itself, and the interpretation of the fire analysis tool outputs and results.

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[1] 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 alternate context. However, the term also has a long history of use in Fire PRA and is used in this standard based on that history common Fire PRA practice.

fire protection defense-in-depth: The principle of providing multiple and diverse fire protection systems and features that will, collectively, prevent fires from starting; detect rapidly, control, and extinguish promptly those fires that do occur; and provide protection for SSCs important to safety so that a fire that is not promptly extinguished by the fire suppression activities will not prevent the safe shutdown of the plant (derived from 1OCFR5O, Appendix B, Sec. II.A [7]).

fire protection design elements: Any aspect of the fire protection program that is supported by specific design requirements and/or analyses.

fire protection feature: Administrative controls, fire barriers, means of egress, industrial fire brigade personnel, and other features provided for fire protection purposes (NFPA 805 [5]).

fire protection program: The integrated effort involving equipment, procedures, and personnel used in carrying out all activities of fire protection. It includes system and facility design, fire prevention, fire detection, annunciation, confinement, suppression, administrative controls, fire brigade organization, inspection and maintenance, training, quality assurance, and testing (RG 1.189 [4]).

fire protection program element: Any specific aspect or provision included as a part of the fire protection program.

fire protection system: Fire detection, notification, and fire suppression systems designed, installed, and maintained in accordance with the applicable NFPA codes and standards (NFPA 805 [5]).

fire-resistance rating: The time, in minutes or hours, that materials or assemblies have withstood a fire exposure as established in accordance with an approved test procedure appropriate for the structure, building material, or component under consideration (NFPA 805 [5].

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 scenario selection: The process of defining a fire scenario to be analyzed in the fire PRA that will represent the behavior and consequences of fires involving one or more fire ignition sources. Fire scenario selection includes the identification of a fire ignition source (or set of fire ignition sources); secondary combustibles and fire spread paths; fire damage targets, detection and suppression systems and features to be credited; and other factors that will influence the extent and timing of fire damage.

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 wrap: A localized protective covering designed to protect cables, cable raceways, or other equipment from fire-induced damage. Fire wraps generally provide protection against thermal damage.

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).[2]

high-energy arcing fault: Electrical arc that leads to a rapid release of electrical energy in the form of heat, vaporized copper, and mechanical force.

high-hazard fire source: A fire source that can lead to fires of a particularly severe and challenging nature. High-hazard fire sources would include, but are not limited to, the following: catastrophic failure of an oil-filled transformer, an unconfined release of flammable or combustible liquid, leaks from a pressurized system containing flammable or combustible liquids, and significant releases or leakage of hydrogen or other flammable gases.

hot short: Individual conductors of the same or different cables coming in contact with each other 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 failure event: 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 (ASMERA-2002/RA-Sb-2005 [2]).

ignition frequency: Frequency of fire occurrence generally expressed as fire ignitions per reactor-year.

ignition source: Piece of equipment or activity that causes fire (RG 1.189 [4]).

ignition target: See "target."

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 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 (ASME-RA-2002/RA-Sb-2005 [2] and ANSI/ANS-58.21-2007 [1]).

Inter-cable (as in inter-cable conductor-to- conductor short circuit): Electrical interactions (shorting) between the conductors of two (or more) separate electrical cables (also see "intracable").

[2] definition has been adapted to suit Fire PRA needs from the definition of "Accident Sequence" as provided in ANSI/ANS-58.21-2007 [1]. A variety of equivalent terms have been used in other Fire PRA related documents including, but not limited to, postfire safe shutdown model, Fire PRA model, and postfire plant response model.

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 off-site power not caused by another external event is considered to be an internal event (ASME-RA-2002/RA-Sb-2005 [2]).

intracable (as in intracable conductor-to- conductor short circuit): Electrical interactions (shorting) between the conductors of one multiconductor electrical cable (also see “inter-cable”).

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 (ASME-RA2002/RA-Sb-2005 [2]).

large early release: The rapid, unmitigated release of airborne fission products from the containment to the environment occurring before the effective implementation of off-site emergency response and protective actions such that there is a potential for early health effects (ANSI/ANS-58.21-2007 [1] and ASME-RA-2002/RA-Sb-2005 [2]).

large early release frequency (LERF): Expected number of large early releases per unit of time (ANSI/ANS-58.21-2007 [1] and ASMERA-2002/RA-Sb-2005 [2]).

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 (ASME-RA2002/RA-Sb-2005 [2]).

Level 1 analysis: Identification and quantification of the sequences of events leading to the onset of core damage (ANSI/ANS-58.21-2007 [1] and ASME-RA-2002/RA-Sb-2005 [2]).

licensee-controlled area: Areas of the plant site that are directly controlled by the nuclear power plant licensee.

limiting failure threshold: Given a set of damage targets, the failure threshold associated with the first fire-induced failure of any member of that target set.

limiting failure mechanism: Given a set of damage targets, the failure mode associated with the first fire-induced failure of any member of that target set.

may: Used to state an option to be implemented at the user’s discretion (ANSI/ANS-58.21-2007 [1] and ASME-RA-2002/RA-Sb-2005 [2]).

multi-compartment fire scenario: A fire scenario involving targets in a room or fire compartment other than, or in addition to, the one where the fire was originated.

multiple spurious operations: Concurrent spurious operations of two or more equipment items.

physical analysis units: The spatial subdivisions of the plant upon which the fire PRA is based. The physical analysis units are generally defined in terms of fire areas and/or fire compartments under the plant partitioning technical element.

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 multiunit site) (ANSI/ANS-58.21-2007 [1]).

point estimate: Estimate of a parameter in the form of a single number (ANSI/ANS-58.21- 2007 [1] and ASME-RA-2002/RA-Sb-2005 [2]).

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)] (ASME-RA-2002/RA-Sb-2005 [2] and ANSI! ANS-58.21-2007 [1]).

probability of non-suppression: Probability of failing to suppress a fire before target damage occurs.

PRA configuration control program: The process and document used by the owner of the PRA to define the PRA technical elements that are to be periodically maintained and/or upgraded and to document the methods and strategies for maintenance and upgrading of those PRA technical elements (ANSI/ANS-58.21- 2007 [1], but it is referred to as "P(Configuration Control Plan").

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, but are not limited to, 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 (RG1.189 [4]).

reactor-year: A calendar year in the operating life of one reactor, regardless of power level (ASME-RA-2002/RA-Sb-2005 [2]).

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? (ANSI/ANS-58.21-2007 [1] and ASME-RA-2002/RA-Sb-2005 [2]).

risk-relevant consequences: The fire-induced failure of any risk-relevant target or the fire-induced creation of environmental conditions that may complicate or preclude credited post-fire operator actions.

risk-relevant ignition source: Any ignition source considered in the fire PRA fire scenario definitions that could cause a fire that might induce a plant initiator or adversely affect one or more damage targets.

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 "Signification Basic Event" as defined by ASME-RA-2002/RA-Sb-2005 [2].

safety function: Function that must be performed to control the sources of energy in the plant and radiation hazards (ANSI/ANS-58.2l- 2007 [ii]).

screening: A process that eliminates items from further consideration based on their negligible contribution to the probability of an accident or its consequences (ASME-RA-2002/RA-Sb-2005 [2]).

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 (ANSI/ANS-58.21-2007 [1] and ASME-RA-2002/RA-Sb-2005 [2]).

secondary combustible: Combustible or flammable materials that are not a part of the fire ignition source that may be ignited if there is fire spread beyond the fire ignition source.

severity factor: Severity factor is 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 (ANSI/ANS-58.21-2007 [ii and ASME-RA-2002/RA-Sb-2005 [2]).

should: Used to state a recommendation (ANSI/ANS-58.21-2007 [1] and ASME-RA-2002/RA-Sb-2005 [2]).

significant contributor: (a) In the context of an accident sequence, a significant basic event or an initiating event that contributes to a significant sequence. (b) In the context of an accident progression sequence, a contributor that is an essential characteristic (e.g., containment failure mode, physical phenomena) of a significant accident progression sequence and if not modeled would lead to the omission of the sequence; for example, not modeling hydrogen detonation in an ice condenser plant would result in a significant LERF sequence not being modeled (RG 1.200 [8]). In the context of fire PRA, the following is also included: (c) a fire ignition source, physical analysis unit, or fire scenario that contributes to a significant sequence.

skill-of-the-craft actions: those actions 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).

spurious operation: The undesired operation of equipment resulting from a fire that could affect the capability to achieve and maintain safe shutdown (RG 1.189 [4]).

state-of-knowledge correlation: The correlation that arises between sample values when performing uncertainty analysis for cutsets consisting of basic events using a sampling approach (such as the Monte Carlo method); when taken into account this correlation results, for each sample, in the same value being used for all basic event probabilities to which the same data apply (ASME-RA-2002/RA-Sb-2005 [2]).

statistical model: A model in which a modeling parameter or behavior is treated as a random variable with specified statistical characteristics.

support system: A system that provides a support function (e.g., electric power, control power, or cooling) for one or more other systems (ANSI/ANS-58.21-2007 [1] and ASME-RA-2002/1{A- Sb-2005 [2]).

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 (NUREG/CR-6850—EPRI TR1011989 [6]).

target set: A group of damage targets that will be assumed to suffer fire-induced damage based on the same damage criteria and damage threshold in any given fire scenario. Discussion: The collection of target sets associated with a fire scenario often represents a subset of the damage targets present in the fire compartment but may also encompass all risk-relevant damage targets in a single physical analysis unit or a collection of damage targets in multiple physical analysis units. This definition implies that all members of any single target set will be assumed to fail when the first member of the target set fails (i.e., ". . . damage based on the same damage criteria and damage threshold"). Progressive or time-dependent states of fire damage may be represented through the definition of multiple target sets for a single fire scenario (e.g., cables in raceways directly above a fire source versus cables in raceways remote from the fire source). The level of detail associated with target set definition will generally parallel the level of detail employed in fire scenario selection and analysis (e.g., screening level analysis versus detailed analysis).

transient combustible: Combustible materials that are not fixed in place or an integral part of an operating system or component (RG 1.189 [4]). (Note that the term "component" as used in this definition is considered interchangeable with the terms "equipment" or "piece of equipment" as those terms are used in this standard.)

transient ignition source: Temporary ignition source that is usually associated with, but not limited to, maintenance or modifications involving combustible and flammable liquids, wood and plastic products, waste, scrap, rags, or 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 (ANSI/ANS-58.21-2007 [1] and ASMERA-2002/RA-Sb-2005 [2]).

verify: To determine that a particular action has been performed in accordance with the requirements of this standard, either by witnessing the action or by reviewing records (ANSI) ANS-58.21-2007 [1]).

walkdown: Inspection of local areas in a nuclear power plant where structures, systems, equipment, and cables are physically located in order to ensure 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 (ASME-RA-2002/RA-Sb-2005 [2] and ANSI/ANS-58.21-2007 [1]).

F
SUMMARY OF TESTING AND PEER REVIEW

F.1 Objective

Two important steps in the development of the Joint EPRI/NRC-RES fire HRA guidelines were subjecting the guidelines to an independent peer review, and subjecting the processes included in the guidelines to some level of 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.

Both the peer review and the testing exercise were highly valuable to the development of this document. As a result of lessons learned and feedback received from both the peer review and the testing exercises, the methodology and documentation underwent a number of revisions. The project team is very 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 these exercises are provided in the sections that follow.

F.2 Peer Review Exercise

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 such that the methodology could be 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 that they were 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 his or her feedback and submitted this documentation to the guidance development team. Each of the comments 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 a number of changes were made to the document and to the scoping trees to prepare them for hands-on testing.

F.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 methods usability when practically applied. The testing conducted as a part of this project did not constitute a verification or validation of the methodology results. Due to the limited availability of adequate detailed HRA data, a quality verification and validation (V&V) analysis is not feasible and is therefore outside the scope of this analysis.

For the purposes of this project, "reasonableness" was defined as yielding HEP values that a) were generally *logical from a 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. 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 plants 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 done 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 boiling water reactor (BWR) and the other a pressurized water reactor (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.

F.3.1 Test Plan

Objective

Exercise fire HRA method broadly enough to evaluate adequacy of analysis guidance and test applicability of scoping and detailed HRA approaches.

Results should identify areas where guidance is insufficient or where improvements to 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., the new HEP values are not lower than the internal events values nor greater than the screening values).
2. If possible also apply the EPRI CBDT approach and compare with the internal events assessment.

   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 HFEs have been identified and included in the PRA models.

Step 1. Prior to plant visit

- Obtain copy of existing fire PRAs and relevant plant procedures (EOPs, FEPs, 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 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, test the fire HRA Method’s identification and definition process, independently. Try to apply the feasibility criteria in the identification and definition step.

- If 6850 HRA screening approach was used, revisit screening analysis to see if revised screening approach provided in fire HRA method would lead to different results for long-term events.
- Identify 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:
  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 etc.
     b. Potential fire/smoke effects ex-control room
  3) Fire response actions
     a. Fire manual actions (FMAs) – including preventative and reactive type actions per NUREG-1852)
     b. HFEs with potential fire effects on instrumentation (EOC and EOOs)
  4) HFE(s) from MCR abandonment due to habitability scenario
  5) HFE(s) from alternative shutdown scenario – fire could introduce problems with controlling safe shutdown equipment, but non-abandonment scenario
- 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 CBDT approach, to selected HFEs.
  – Support will be needed from training and other plant personnel to make scoping path selections and to provide needed information (e.g., for information on requirements for ex-control 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 we need to then provide the results to the plant and ask for feedback. Are the results what you need to complete the FPRA? Are the results reasonable and are there any actions that you would require detailed analysis on based on the results the scoping trees? Question to the plant: What are you thoughts on the method application?

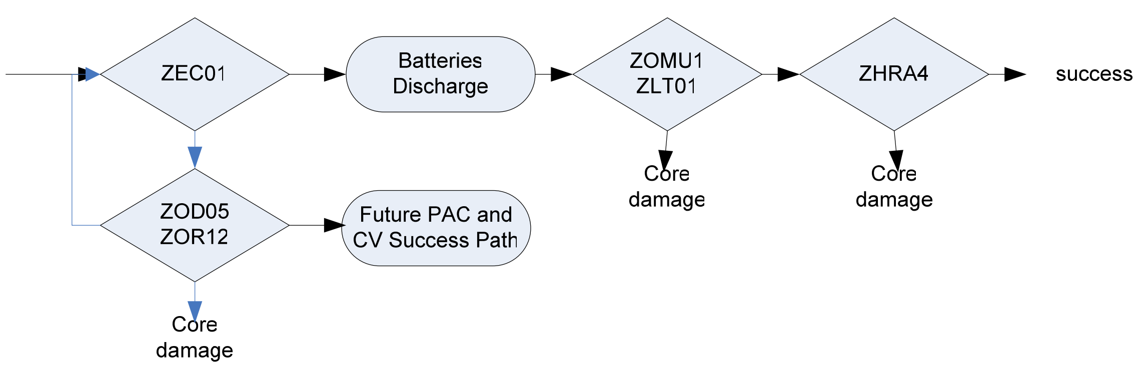
F.3.2 Testing Scenarios Plant #1

Prior to the plant visit, the project team was provided with a set of plant procedures. A set of five scenarios were proposed for use in evaluating the scoping methodology on Plant #1. They included one or more scenarios in the five categories of (1) Existing internal events that are important to the fire PRA, (2) New FPRA 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 below:

F.3.2.1 Existing Internal Events HEPs Important to FPRA Fire Scenario

Fire starts in the turbine building causing loss of offsite power and 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 following operator actions are important relative to reaching a success state:



- ZEC01 – controlling emergency condensers per procedures, which instruct operators to stay within pressure band and cool down rate. Operators will isolate one EC relatively early and eventually isolate the second and then unisolate the second EC to control RPV pressure (and cool down 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 sufficient inventory will be lost resulting in blow down at 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 they isolate per cool down and then ZOU01 or 02 is required to ensure 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 use of portable charger a success path is possible as described above for ZEC01.

- ZHRA4 – when batteries discharge (4 to 8 hours dependent 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, 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.

F.3.2.2 New FPRA HEP Not in the Internal Events PRA

There are potentially a few new operator actions not in the internal events PRA but that are 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.

F.3.2.3 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 main condenser, if available initially (water in the steam lines); there are probably fires that take both main condenser out and start overfill. EC actuation with water in the EC steam lines could result in EC isolation (assumed in the PRA).

Fire Scenario – 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

F.3.2.4 Spurious/False Indication Causes Inappropriate Operator Action Fire Scenario

Fire starts in reactor building (e.g., R2A or 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 most important because fires in T3B can also impact feedwater and or normal AC power making the ECs important. Plant #1 assumed ECs would become unavailable without recovery and therefore did not pursue more detailed evaluation.

F.3.2.5 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 special breathing 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-A5 is assumed to cause failures in breaker control switch circuits on these Main Control Room panels such that buses 101, 102, 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 their power feeds, thereby causing loss of all loads on these buses/boards. Offsite power actually remains available – it needs to be re-provided to the buses/boards by reclosing of necessary breakers though it is assumed 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 speeding up 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), 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), and the overfill condition is assumed to make the emergency condensers (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.

F.3.3 Testing Scenarios Plant #2

Prior to the plant visit an engineer from plant #2 provided the project team with 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 that were chosen were modeled in the plants 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.

The table below lists the scenarios that were tested, the scenarios classification, and the flow charts that were used to test them.

Scenario #	Description	Classification	Flow Charts 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 & 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 & Existing Ex-CR action
4	Operator responses to spurious 4KV Bus F ground annunciator	Undesired operator response action	Spurious EOO and Spurious EOC
5	Operator fails to de-energize PORV/closed to mitigate spurious operation during MCR abandonment	New action added for FPRA	MCR abandonment

The scenarios are described below:

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 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 (800b) 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, Aux Feedwater successful, BUS G ECCS equipment is impacted by fire
3. Operator Actions preceding the key action: Controlled ECCS flow to match make-up flow with leakage rate. Tripped RHR pumps
4. Symptoms/ Indications (Other than the 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
8. Manipulation time: 25 minutes
9. Tsw=120 minutes +180 minutes
10. Tw=Tsw-Tm=95 minutes

Scenario #2: Heat load reduction/swap to alternate CCW train

The fire starts in the 125V DC 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 simultaneous 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 M10). 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. TSW=90 minutes
10. Tw= Tsw-Tm=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 simultaneous with fire alarm actuation in the control room. AFW pumps 1 and 2 are impacted and LCV is impacted

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, 480V switchgear ventilation and AFW FTs. AFW pump 1-2 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. TSW= 135 minutes
10. Tw= TSW – TM = 120 minutes

Cue: Fire alarm actuated. Decreasing SG level all SG and level instrumentation avail

Scenario #4: Operator responses to spurious 4KV Bus F ground annunciator

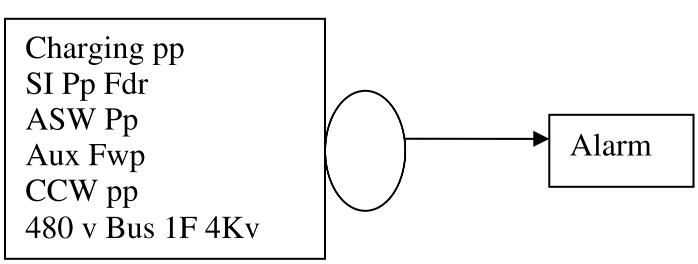
In order to test the spurious EOO and EOC flow charts the plant provided the following example of an HFE they identified in their review of ARP procedures. The review of the ARP was performed in accordance with the guidance in Section 3 of the draft guideline. The complete fire scenario was not provided or defined since this action has not yet been incorporated into the FPRA. The analysis for this HFE focused on how to use the flow chart and it was concluded that the spurious flow charts need additional clarification.

Scenario Description

The following annunciator spuriously actuates in the control room

AR PK-18-23 – 4KV Bus F Ground OC Alarm

The logic for the 4KV Bus F ground is shown below



Step 5 of the procedure is the following steps

5.1 Check annunciator typewriter printout for equipment having the group.

5.2 Shutdown the running pump or open 4KV 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 their FPRA model. Therefore the team created a fictitious scenario to test the MCR Control Room abandonment flow charts.

Description of action: Operator fails to de-energize 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- 6850 MCR abandonment criteria are met.

Tsw = 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, DSDP.

F.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 gain insights on how they would execute the procedures given the specific fire scenarios. The intention was to find areas where the operators could potentially be tripped up by the circumstances of the scenarios and to figure out whether the assumptions that were 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 that he provided. This exercise gave the team a number of insights on how the logic in the charts held up given realistic scenarios. The plant engineer also provided the team with some suggestions on minor adjustments that could be made to improve the charts.

F.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 flow charts performed given realistic scenarios. The team also got an opportunity to introduce the methods to some of its potential users and get their feedback. The plant personnel at both plants posed a number of insightful questions, and made valuable suggestions on how to improve the scoping flowcharts. The interviews with the plant personnel prior to testing the flowcharts also provided the team with insights on how the operators are trained, how they use their procedures, and how they use their instruments to diagnose problems. This gave the team a better idea how well the scoping trees actually modeled operator actions.

For example, during the interviews at plant number #2, the operators emphasized that they would not open the fire procedures until they had completed the emergency operating procedures (EOPs) because they trusted that the EOPs would guide them correctly.

A number 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 per 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 the wording.

In general the HEPs derived at Plant #1 through the use of the scoping flowcharts were conservative when 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 resulted in the overly conservative HEP results.

Overall the plant engineers at both plants thought 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 a number of 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.

G
HRA ASSOCIATED WITH FIRE-RELATED ELECTRIC BUS CLEARING AND RESTORATION PROCEDURES

G.1 Objective

The fire HRA guidance provided in the main body of this report is expected to be applicable to the majority of scenarios, but may need to be adjusted or expanded to address certain special cases.

Revision 1 to Regulatory Guide 1.189 (dated March 2007), “Fire Protection for Nuclear Power Plants” describes certain Assumptions under its stated Fire Protection Program Goals/Objectives. One such assumption (on page 17) discusses a special case involving Loss of Offsite Power/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 post-fire 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 need for operator manual actions after a fire. However, acceptable operator manual actions that are implemented in accordance with Regulatory Position 5.3.3 and NUREG-1852, "Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire" may present a lower risk than the SISBO approach.

NUREG-1852 does not specifically address SISBO situations but rather provides a set of "criteria and associated technical bases for evaluating the feasibility and reliability of post-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 5.3.3 of Rev. 1 to Reg Guide 1.189 states that "The post-fire safe-shutdown analysis should describe the methodology necessary to accomplish safe shutdown, including any operator actions required,' but also that required protection of redundant systems located in the same fire area per Appendix R, Sections III.G.1 or III.G.2 must be provided.

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 operator manual actions are considered feasible and reliable per the criteria in NUREG-1852.

According to reviews of fire PRAs conducted by Brookhaven National Lab in 1995, eight units have procedures that require initiating a station blackout (SBO) condition to comply with Appendix R/NFPA-805 requirements and an additional fifteen units have procedures for dealing with fires in critical areas that could result in an SBO.

As this indicates, 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 in a fire zone unrelated to the selected train of equipment and the operators would therefore want to isolate that bus since they are protecting a train. For plants where uncertainty exists about equipment wiring schemes, the preference might be to clear out and start over to ensure they do not have a short or ground that would cause problems on the preferred bus. However, since 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 appendix provides some considerations for evaluating HRA issues for NPPs that use FEPs to clear electrical faults associated with fire induced spurious events. Because plant-specific variations and explicit guidance for performing fire HRA cannot be provided here, this appendix instead includes some general recommendations for how fire HRA tasks might need to be performed differently in order to address the HRA issues of concern for fault clearance strategies.

These recommendations have been organized consistent with the structure of the main body of this report, first discussing identification and definition of Human Failure Events (HFEs), then quantitative screening, followed by qualitative analysis, and finally quantification of HEPs with respect to issues associated with clearing electrical faults.

G.2 Identifying and Defining HFEs

As discussed in Section 3.1 of the main report, this step of the fire HRA addresses (1) the identification of operator actions that are necessary for successful mitigation of fire scenarios, and (2) representation of these operator actions through the definition of human failure events (HFEs) that are modeled in the fire PRA.

Implementation of some fire procedures use fault clearance strategies to ensure that a cooling train is protected if portions of a required bus are within the effected zone. Consequently, the fire HRA must make use of input from procedures, Appendix R/NFAP-805 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.

To identify operator actions taken in response to a fire, a detailed review of the FEPs is needed to examine the cues and procedure steps. In addition, it is important for the analysis to review the plant-specific training on the procedures, and conduct an in-plant visit to the locations where an action would be taken to identify new actions that introduce HFEs into the fire PRA model.

The following are some issues that should be considered in identifying and defining HFEs for the fault clearance scenario through the review of FEPs:

1. Successful safety functions require success of specific operator actions that can be identified in the FEPs. These actions are selected for inclusion in the HRA. Operator actions identified by Fault Tree logic, pertaining to system alignment, are also included. Typical emergency procedures, alarm response procedures and normal or abnormal operating procedures (prefixed: EOP, ARP, and AOP) are used as bases and sources for selecting the subtasks for the specific operator actions.
2. Once the FEPs are entered in response to a fire in a specific location, the cues for action are determined by the procedural steps and checking with the control room supervisor rather than cues from parameters in control room. Each subtask is selected for modeling on the basis that failure of the operator to perform that specific step would significantly impact or result in failure of a safety function or system.
   - For example, assuming fire induced FEP entry conditions exist, failure to implement the function(s) implies that non-recovered equipment unavailability, LOCA, or interfacing LOCA conditions also exist, and lead to core damage.
   - Most monitoring and checking steps are screened out if they are follow-through from or to an operator action, and do not involve some physical operator activity. Such actions typically involve steps for verifying expected system parameters while performing other major (physical) steps.

3. The assumption is that if the plant response is normal or as expected for the accident scenario, then normal system parameter responses would be attained, and no new actions would be triggered.
4. The HRA review of the FEP needs 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, and other performance shaping factors.
5. The same function may be called for in different steps in the FEPs, or different functions impacted within the same FEPs.
6. If unexpected conditions occur during the application of FEPs 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.
7. PRA modeled paths through the plant procedures are pre-identified through the review of the plant procedures that organize the FEPs for a specific fire zone to identify the specific response associated with each step in the overall fire procedure, including both major parts and attachments.
8. The path through the procedures is dependent on the preceding events in the PRA event tree and zone specific FEPs.
9. Secondary cues provide a basis for using alternate cooling paths. Operators can initiate a new response based on the Critical Safety Function Status Trees (CSFSTs) or alarms, for example. These provide the opportunity for recovery of an HFE if the initial cues or directives are missed. This is particularly useful if the alternate cooling path is provided by a different crew member than the primary path.
10. The success criteria of the events modeled in the PRA event tree follow the Level 1 model, with some additional fire specific conditions considered (transition to cold shutdown has no time requirement, and the operators will be able to verify operability of all needed components before initiating the transition to cold shutdown, therefore if hot shutdown is successful, then the likelihood of cold shutdown failure is nil).
11. Several operator actions may be required in order for success of a specific system or function. In addition, these multiple actions may be performed in multiple locations (including field locations) by multiple operators. Furthermore, communication between the various performers may need to be coordinated or sequenced in a particular way, requiring communication between the various operators. In such cases, analysts might consider modeling separate HFEs for the decision-making and execution actions that must fail together, if the system or function is to fail. For example, the decision-making and action-coordinating parts that are likely to be performed by control room operators can be modeled as one or more actions. (If either of these types of actions fail, then field actions also must fail.) Separately (if control room decision-making is successful), analysts would model HFEs that represent the failure of executing field actions (possibly different HFEs for different locations).

In an example for the specific case of fault clearance, according to some plant designs, operator actions are required within fire emergency procedures (FEPs) 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 operator success involves two distinct phases of valve alignment when entering the FEPs:

1. If the operator is successful in implementing the FEP reset steps by de-energizing 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 FEPs by re-energizing the appropriate electrical buses, and ensuring that at least one train of cooling is operating.
3. Operator errors during either the reset or realignment steps are assumed to leave key valves and components that are modeled in the PRA in the wrong position (e.g., blocks the initiating of the specified cooling train, could also initiate a LOCA or fail to block a spuriously induced LOCA) and should therefore be included as HFEs in the fire PRA model.

G.3 Quantitative Screening

The method discussed in Section 4.2 of the Guidelines 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 on going activities in the accident sequence), and ensuring that potential dependencies among HFEs modeled in a given accident sequence are addressed.

Screening Set 1 criteria apply only to pre-existing HFEs in the Internal Events PRA. 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 criteria address (1) new HFEs added to the fire PRA or (2) prior Internal Events PRA HFEs needing to be significantly altered or modified in Step 1 of this procedure because of fire conditions, and are therefore considered to be the screening criteria applicable to the fault clearance scenario.

Depending on the Set 3 criteria below, 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.

G.3.1 Set 3 Criteria

1. If the action being considered is either a MCR or local (i.e., ex-control room) manual action and it 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 thus not continuing to cause delayed spurious activity and other late-scenario complicating disturbances, and that there is plenty of time available to diagnose and execute the action, set the HEP to 0.1 for screening or 10 times the internal events HEP which ever is lower for the initial action.
3. The analyst still needs to ensure that potential dependencies across HFEs in the models and the joint probabilities of multiple HEPs in the same sequence are accounted for per the ASME Standard [2]. That is, 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 for the second and third HEPs that appear in the sequence, or dependencies accounted for by separation of events or questions in the scoping process, or in methods associated with the detailed quantification. The main difference between the first and second group in this criteria set is that the fire is assumed to be out after the first hour.

G.4 Qualitative Assessment

The qualitative assessment portion of the fault clearance scenario evaluation should be performed consistent with the discussion in Section 5 of the main report, since a thorough evaluation would be needed of the context, Performance Shaping Factors (PSFs), procedures and training, complexity, workload/stress, human machine interface (HMI), environment, special equipment needs, and crew dynamics.

One process which 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 shown below.

Cue |→ Error → Failure of Recovery → Failure Event.

|→ Success → New cue or Success Event.

This structure facilitates the evaluation of success and failure states that are needed for modeling the procedure selection between EOPs and FEPs allowing the analysis to focus on those 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. First is clearing the bus or circuit by removing power. The second is restoring the section of the bus or circuit needed to operate a selected safe shutdown cooling configuration. Within each main step there are many opportunities to define HFEs from the procedures. Also, the workload from these additional steps should also be considered in qualitatively evaluating each HFE.

G.5 Quantification

It is expected that HFEs associated with the bus clearing strategy scenarios will be quantified using detailed HRA quantification. For this type of situation, it is not recommended to use the scoping trees provided in Section 6.2 of the main report due to 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 using the EPRI HRA methodology approach presented in Appendix C of this report or the ATHEANA HRA method (NUREG-1880) [2] presented in Appendix D. With appropriate consideration of the fire context as described in Section 5 of this report (Qualitative Analysis), the two detailed HRA methodologies presented can be used to address fire-specific issues and PSFs.

Among the PSFs which could be expected to be important for the fault clearance scenarios would be:

- complicated procedures and potential interaction between EOPs, AOPs and FEPs, particularly the consideration of hesitancy by operators to enter procedures that might require SISBO,
- difficult communications (e.g., involving SCBAs) between control room and field operators,
- coordination of multiple actions, and
- field actions in a variety of locations (with possibly different environmental conditions to be reflected).

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

1. Detailed modeling is required for unscreened fire zones where additional attachments or parts called for in FEP entry procedures have the potential for a loss of safety functions due to errors in applying these modified parts and added attachments.
2. Detailed modeling is required for conditions prior to entering the FEPs 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.
3. Top events identified in the IPEEE 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.
4. The HEPs for HFEs associated with staying in the EOPs are lower than those for implementing the FEPs in many cases. This is an operator decision that impacts whether the clearing and restoring actions are carried out.
    - The choice of procedures to use can significantly impact the HEP for the fire zone.
    - An assumption for initial modeling of the HEP is that given the fire was not put out quickly; the operators always go directly to the FEPs.

- Use of FEPs is delayed until the operators cannot control the plant.
- A detailed decision model is needed to evaluate the error potential associated with decisions that the operators could make for either entering the FEPs from the EOPs or not.
- Data for implementing this model can be obtained through operator interviews. An interview form can be used to record the results.

5. If abnormal conditions arise due to independent equipment failures prior to FEP implementation, only equipment that is re-positioned or verified within the FEPs steps are recovered. Cues for equipment failures outside the FEPs or after application of FEPs are assumed to be unobserved and not recovered in the model contributing to the HEP value.
6. Once 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 are omitted or performed incorrectly; and the approximate time window for success associated with the scenario is based on the deterministic safe shutdown assessment documented in the Fire Hazards report. These include immediate actions, those within 30 minutes, those within 90 minutes and longer term actions.

G.6 References

1. Regulatory Guide 1.189, "Fire Protection for Nuclear Power Plants", U.S. Nuclear Regulatory Commission, Washington, DC, Revision 1, March 2007.
2. FIN L-2629, Brookhaven National Laboratory, Draft Technical Letter Report, "Risk Evaluation of the Response of PWRs to Severe Fires in Critical Locations", May 30, 1995 (Draft Predecisional).
3. FIN L-1311, Brookhaven National Laboratory, Technical Evaluation Report, , "A Risk-Based Approach for Evaluation of Fire Mitigation Features in Nuclear Power Plants", November 21, 1995 (Draft Predecisional).

H

JUSTIFICATION FOR SCOPING APPROACH

This appendix addresses the basis for the scoping quantitative approach. Issues include why the demonstration of feasibility and use of time margins are required, what PSFs are addressed implicitly and explicitly, and what the basis is for the HEP values assigned through the use of the flowcharts.

H.1 Demonstration of Feasibility

The feasibility demonstration outlined in Section 5 is conducted to exhibit that a given action or set of actions for a HFE can be diagnosed and performed within the time available. Of primary importance within the demonstration is the consideration of the timing of the event and the action. An operator action is considered feasible if the time available exceeds the time required. As discussed in Sections 4 and 5 of this document, the time available is typically derived from thermal-hydraulic studies and is the time from the initiating event (fire induced reactor trip) until an undesired or irreversible plant damage state is reached (e.g., core damage).

Demonstrating the time required to formulate and execute a response can be problematic. Under normal conditions, walk-throughs, or even talk-throughs, with control room operators can be used to estimate this time. However, a fire situation represents less than optimal conditions that can greatly impact the crew performance during diagnosis and execution. Thus, for the HFEs modeled in the fire PRA, the conditions under which the diagnosis and execution will have to take place should be carefully addressed, and it is even more important that the estimation of the time required should be made during well structured demonstrations performed under as realistic circumstances as possible.

In addition to showing that the action can be performed in the time available, the demonstration also includes inherent characteristics of the action such as complexity, the retrieval of needed tools, the wearing of SCBAs (if expected to be required), and other factors that could affect performance. By directly including these conditions in determining the feasibility of the actions, there are fewer PSFs and conditions that need to be estimated in determining the HEPs using the fire scoping HRA approach and uncertainty is reduced.

However, there are a number of situations or factors in the fire context that may be very difficult to recreate. For instance, simulating a smoky environment is beyond the scope of a walk-through demonstration. Thus, although the demonstration lends confidence that the action is feasible under the assumed conditions, it is necessary to show that there is some additional time available (i.e., a time margin) in order to have some confidence that the effects of factors that could not be simulated or predicted, would not usually prevent the action from being completed.

H.2 Time Margin

The time margin (the difference between the available time and the time required, essentially the extra time available) is included not only to account for potential shortcomings in the ability to adequately simulate the actual plant conditions during the demonstration, 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.

As discussed in section 5.2.2, ideally, in order to get as realistic estimate of the time required to perform the actions as possible, several crews would be used in conducting the demonstrations. However, since this may not always be possible and data from one crew may not be representative of all crew response times, 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 potentially poor performance of expert judgment in predicting the amount of time required for aspects of the response that cannot be simulated, especially under stress [1]. Specifically, the extra time is included to account for potential unexpected fire effects and variabilities such as:

- Individual differences
- Crew differences
- Variations in fire type and related plant conditions
- Factors unable to be recreated in the feasibility demonstration

NUREG-1852 [2], in addition to providing the guidance for demonstrating the feasibility of the relevant actions that the guidance in Section 5 of this document is based on, also provides guidance for 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. Although in some cases HEPs assuming smaller time margins are provided, these HEPs are increased. Similarly, in some special cases, a time margin greater than 100% is required to obtain the 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 post-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. It should be noted that a factor of 2 time margin is consistent with ANSI/ANS Standard 58.8 [3], which addresses time response design criteria for safety-related operator actions.

There are circumstances within the scoping flowcharts when a different time margin is required. Extended time margins (e.g., 200% or a factor of 3) are required in the presence of certain conditions (e.g., short vs. long time frame events or simple vs. complex actions) when the effects of the fire may be greater and induce larger variability in crew response times.

H.3 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 [4] and those discussed in NUREG/CR-6850 [5], which are based on reviews of fire events.

Before entering the scoping flowcharts, there are a minimum set of PSF criteria that must be met. As described in Section 5 of this document, meeting these minimum criteria does not preclude the consideration of these PSFs later in quantification. First, there must be plant procedures in place supporting the diagnosis and execution of the operators' action(s) being modeled, unless the action can be assumed to be skill-of-the-craft.1 Next, the operators should be trained on the use of the procedures and the actions being performed. This training on the action should include 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 have been established, there are PSFs that must be addressed within the demonstration of feasibility. Section 5 of this document outlines explicitly which PSFs should be addressed and provides guidance on how to perform the demonstration and assessment. The factors addressed in the demonstration (including: environment, equipment functionality and accessibility, available indications and MCR response, communications, portable equipment, personnel protection equipment, procedures and training, and staffing) could be impacted by the fire and are especially important in calculating the time to perform the action.

Finally, a number of PSFs are addressed explicitly within the flowcharts. Some of these PSFs are covered within the flowcharts because it is likely they were unable to be simulated in the demonstration of feasibility. However, other of the PSFs addressed explicitly in the flowcharts may have been covered to some extent in the demonstration of feasibility as well (e.g., the complexity of the task is an inherent characteristic that will be part of the demonstration). They are explicitly addressed in the flowcharts as it is expected that these PSFs could induce significant variability in crew performance and response times and it is important that they are adequately addressed.

[1] 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 [4].

The PSFs explicitly addressed through the flowcharts include:

- 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 straight forward.
- Execution complexity – The execution complexity of the response is quantified at two levels, either high or low. Section 5 of this document 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 [5] and FAQ 50 [6], most fires are extinguished or contained within 60 minutes of the start of the fire.[2] The measurement of time since start of fire is a contextual variable that is included within the scoping flowcharts as 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 limiting accessibility to the action site; increased distractions in the MCR due to implementing fire procedures and coordinating and tracking the ongoing fire fighting). Greater time margins and/or higher HEPs are assigned to account for these possibilities. Furthermore, if the fire has not been fully suppressed and fire-effects may be ongoing, there are additional PSFs that 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 only asked in the instances where the fire has not been suppressed.
- Length of time window – This is an additional timing question posed in the scoping approach to distinguish between long-term and short-term events. 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 (i.e., the time margin). Within the scoping flowcharts, a distinction is made between long-term events (i.e., events that have more than a 30 minute time window) 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 time frame events. With only a relatively small time window, such distractions could have a proportionally greater impact than when larger time frame events are involved. Within the scoping fire HRA approach, for the shorter time window events (i.e., less than or equal to 30 minutes available), higher HEPs are assigned and a greater time margin is required to achieve a relatively low HEP. These

[2] An important exception to this 60-minutes rule are more challenging fires such as fires of turbine generators, outdoor transformers, high energy arching faults, and flammable gas fires. For modeling of actions during these events, the analyst should always assume the cue occurs before the fire has been suppressed, regardless of when the cues occur relative to the start of the fire.

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.

- 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 special equipment (e.g., SCBA) be worn. In the presence of an on-going fire, these factors are especially a concern. Furthermore, the impact they may have on a crew performing the necessary action may be difficult to simulate in the demonstration of feasibility.
- 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 either due to ongoing fire effects at the place of the action or in the path to the action location. Fire effects limiting the ability to proceed to or through an area may include, but are not limited to, the presence of flames, intolerable heat, water on the floor or in area, high amounts of smoke or other toxin impeding breathing or visibility, and illumination of the area.
- Time margin – As discussed in Section H.2, a measure of time margin is included to account for the uncertainty not directly addressed through the feasibility demonstration or other PSFs included within the flowcharts.

H.4 HEP Values

H.4.1 Optimal 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 [7] as the value for "The operator is 'Extremely Unlikely' to fail" and this definition is consistent with how the value is used in the scoping approach. The specific conditions required to attain the HEP of 1E-3 are:

- Minimum PSF criteria has been met prior to entering the flowcharts,
- Feasibility has been demonstrated,
- Procedures match the scenario, indicating a straightforward diagnostic situation,
- Diagnosis and execution take place within the MCR,
- Fire effects are not ongoing,

- Action time window is greater than 30 minutes,
- Execution complexity is low,
- Time margin is at least 100%.

Although the 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 [8], THERP [9], and ASEP [10]. SPAR-H, in particular was chosen for this comparison as they have made a concerted effort to align their HEPs with other methods [8, 11]. 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 on-going). These methods do not explicitly address obtaining HEPs under fire conditions, so we only use them to show consistency with our "baseline" HEP.

In consideration of the diagnosis component, assuming the diagnosis related conditions noted above 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 extra time being available. 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 in SPAR-H.

The base HEP in the scoping approach is also consistent with that assigned through the use of ASEP [10] for diagnosis within time allowed if 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 due to the diagnosis of the action being relatively simple and straight forward, 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 time frame event (> 30 minutes time 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 [10] are argued to be conservative values.

For quantification of the execution portion of the HEP, SPAR-H [8] 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 [10] 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 can verify the action. Thus, 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 [9] 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 an error of omission and written, procedural direction being available.
2. Table 20-7 offers an HEP value of 1E-3 for there being written procedures 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.

Thus, the assumption of a base or optimal 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 than those obtained for similar conditions using existing methods such as ATHEANA [7], THERP [9], ASEP [10], and SPAR-H [8], and is likely to be conservative relative to the values obtained using the other methods.

H.4.2 HEP Multipliers for PSFs

As conditions deteriorate from this "optimal" condition, Table H-1 shows the multipliers that are 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. In the determination of the HEPs, as the conditions of the scenarios deteriorated or conditions became more negative (for example, time margin of less than 100%, smoke levels high requiring the crew to wear SCBAs), the multipliers were applied cumulatively. In other words, if a situation was 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.

Along with these multipliers, an additional constraint is added to those actions that are either considered to be highly complex or are to be performed in an action time window less than (or equal to) 30 minutes. For these instances, the base time margin level is set to a factor of 3 (i.e., an additional 200% of the demonstrated time). It is reasoned that extra time would be necessary to deal with distractions or problems should they occur while attempting a highly complex action. Similarly, extra time would be needed to buffer problems or distractions that occur when only a short action time window is available.

Table H-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 60 minutes from the start of the fire)	10
Action time window 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

H.4.3 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 flowchart depicted in Figure 5-2). The HEP values assigned when using the other flowcharts (i.e., execution takes place locally, HFE for MCR abandonment or alternative shutdown, or HFE for action(s) in response to an error due to spurious indicators) reflect assumptions about increasing difficulty due to 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 5-3 (EXCR) covering HFEs for actions that are executed locally are two times greater than those HEPs assigned for HFEs covering actions executed within the MCR (INCR, Figure 6-2). 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 MCR abandonment or the use of alternative shutdown (CRAB, Figure 5-4) are five times greater than the HEPs assigned for HFEs involving locally executed actions (EXCR, Figure 5-3). Finally, the HEPs for HFEs covering recovery actions in response to EOOs or EOCs due to spurious instrumentation (SPI, Figure 5-5) 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 5-2). 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 5-3). The multipliers applied to the flowcharts are illustrated in Table H-2.

Table H-2
Calculation of HEP values across scoping flowcharts

Scoping Flowchart	Multiplier Applied to Base Flowchart to Adjust Values in Scoping Flowchart	Base Flowchart
EXCR (Figure 5-3)	2	INCR (Figure 5-2)
CRAB (Figure 5-4)	5	EXCR (Figure 5-3)
SPI (Figure 5-5)	5	INCR (Figure 5-2) for in MCR actions; EXCR (Figure 5-3) for ex-CR actions

An example may help to illustrate the use of the multipliers. A scenario involving the same PSFs is illustrated for each of the flowcharts to demonstrate the application of the multipliers across the flowcharts. The PSFs for the illustrative scenario are:

- Minimum PSF criteria has been met prior to entering the flowcharts,
- Feasibility has been demonstrated,
- 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. < 60 minutes since the start of the fire),
- Area is accessible and there is no fire in the vicinity of the action,
- Action time window 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 (INCR30 from HEP Lookup Table J).3 This same scenario represented as a local, ex-CR action would have an HEP of 0.1 (EXCR31 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 MCR abandonment or alternative shutdown would result in an HEP of 0.5 (CRAB12 from HEP Lookup Table AE), which is equal to five times the ex-CR 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 AK). This value is the same as the HEP for normal in-MCR actions multiplied by 5. Finally, if the recovery is needed to be executed locally as an ex-CR action, the HEP would be equal to 0.5 (SPI28 from HEP Lookup Table AP), which is five times larger than the normal HEP for an ex-CR action.

[3] The HEP of 0.05 can be obtained either by referencing HEP Lookup Table J or by applying the multipliers discussed in Section H.4.2. 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).

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

In 2001, EPRI and the USNRC's Office of Nuclear Regulatory Research (RES) 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 NUREG/CR-6850 (EPRI1011989), entitled "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 identification and inclusion of human failure events (HFEs) into the fire PRA (FPRA), and a methodology 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). However, NUREG/CR-6850 did not describe a methodology to develop best-estimate HEPs given the PSFs and the fire-related effects.

In 2007, EPRI and RES embarked on another cooperative project to develop explicit guidance for estimating HEPs for human failure events under fire generated conditions, building upon existing human reliability analysis (HRA) methods. This document provides a methodology and guidance for conducting a fire HRA. This process includes identification and definition of post-fire human failure events, qualitative analysis, quantification, recovery, dependency, and uncertainty. This document provides three approaches to quantification: screening, scoping, and detailed HRA.

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