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Human Event Repository and Analysis (HERA): The HERA Coding Manual and Quality Assurance

Idaho National Laboratory

U.S. Nuclear Regulatory Commission
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Human Event Repository and Analysis (HERA): The HERA Coding Manual and Quality Assurance

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC), with the support of the Idaho National Laboratory, is developing the Human Event Repository and Analysis (HERA) system to analyze and collect human performance information from commercial nuclear power plants and other related technologies to support regulatory applications in human reliability analysis (HRA) and human factors (HF). Volume 1 of NUREG/CR-6903, dated July 2006, describes the HERA framework, addresses the need for systematic collection of human events, and discusses the various uses of HERA-type data in regulatory applications. To augment that discussion, this volume (Volume 2), describes the HERA data taxonomy, data collection process, and quality control provisions. Specifically, the data taxonomy identifies the types of information to be collected. The HERA data collection process defines an effective, stepwise approach for use in analyzing and collecting human performance information from event reports and simulator studies. Finally, the quality control provisions describe the required qualifications and expertise for data coders, as well as the recommended process for ensuring the quality of HERA data. The software tool and observed human performance insights will be addressed in future volumes of NUREG/CR-6903.

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FOREWORD

The U.S. Nuclear Regulatory Commission (NRC), with support from Idaho National Laboratory, is developing the Human Event Repository and Analysis (HERA) system for use in analyzing and collecting human performance information from commercial nuclear power plants and other related technologies. As envisioned, this system will include the HERA framework, data taxonomy, data collection process, quality control provisions, a software tool, and observed human performance insights. Together, these HERA system components will help to support regulatory applications related to human reliability analysis (HRA) and human factors. In addition, the HERA system will support HRA method developers who seek to understand the relationship between situational context and the operator behavior observed during events.

Volume 1 of NUREG/CR-6903, dated July 2006, describes the HERA framework, addresses the need for systematic collection of human events, and discusses the various uses of HERA-type data in regulatory applications. To augment that discussion, this volume (Volume 2), describes the HERA data taxonomy, data collection process, and quality control provisions. Specifically, the data taxonomy identifies the types of information to be collected. The HERA data collection process defines an effective, stepwise approach for use in analyzing and collecting human performance information from event reports and simulator studies. Finally, the quality control provisions describe the required qualifications and expertise for data coders, as well as the recommended process for ensuring the quality of HERA data. The software tool and observed human performance insights will be addressed in future volumes of NUREG/CR-6903.

Overall, the HERA project supports the NRC's "Plan for the Implementation of the Commission's Phased Approach to Probabilistic Risk Assessment Quality" (SECY-04-0118 and SECY-07-0042). This support is important because practitioners have viewed HRA as one factor that contributes significantly to the uncertainties in probabilistic risk assessment (PRA) results. This contribution is primarily attributable to a lack of quality data to support the evaluation of the human events that are modeled in PRAs. In this context, the "data" comprise information related to human performance. Consequently, in SECY-04-0118, the NRC staff noted that "such a repository [i.e., the HERA system] will mark a significant step towards addressing the issue of quality of data for HRA, viewed by practitioners as a significant limitation of HRA state-of-the-art."

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This report documents lessons learned by the Idaho National Laboratory and collaborators in coding various data sources using the Human Event Repository and Analysis (HERA) system. During preliminary HERA coding efforts, a number of people have made significant technical contributions and suggestions to improve the quality of the coding process. For their efforts we gratefully acknowledge June Cai, Ben Parks, Gareth Parry, and Autumn Szabo from the NRC; Theresa Flores, Don Dudenhoeffer, Tuan Tran, and Steve Meldrum from the Idaho National Laboratory; Alan Kolaczkowski and Dennis Bley, consultants; Helena Broberg, Per Øivind Braarud, Andreas Bye, Michael Hildebrandt, Karin Laumann, and Salvatore Massaiu from Halden Reactor Project; and Ali Mosleh from the University of Maryland.

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ACRONYMS

ADV	atmospheric dump valve
AFW	Auxiliary Feedwater
AIT	Augmented Inspection Team
AITs	Augmented Inspection Team reports
ASP	Accident Sequence Precursor
ATHEANA	A Technique for Human Event Analysis
B&W	Babcock and Wilcox (PWR)
BOP	balance of plant
BWR	boiling water reactor
CAP	corrective action program
CCF	common cause failure
CCDP	conditional core damage probability
CE	Combustion Engineering (PWR)
CI	contextual information (HERA subevent code)
ΔCDP	delta (change in) core damage probability
DNS	date not specified
EDG	emergency diesel generator
EE	external event (HERA subevent code)
EOC	error of commission
EOO	error of omission
EQA	equipment actuation (HERA subevent code)
GE	General Electric (BWR)
HEP	human error probability
HERA	Human Event Repository and Analysis
HF	human factors
HFE	human failure event
HFIS	Human Factors Information System
HMI	human machine interface
HRA	human reliability analysis
HS	human success (HERA subevent code)
I&C	instrumentation and controls
IAEA	International Atomic Energy Agency
INL	Idaho National Laboratory
IR	inspection report
LER	licensee event report
LTA	less than adequate
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NSSS	nuclear steam supply system
NUREG	Nuclear Regulatory Commission Report
NUREG/CR	Nuclear Regulatory Commission Contractor Report
OE	operating experience
OPS	Operations
PIR	problem identification and resolution
PRA	probabilistic risk assessment
PS	plant state (HERA subevent code)
PSF	performance shaping factor

PWR	pressurized water reactor
QA	Quality Assurance
RCA	root cause analysis
RCIC	reactor core isolation cooling
RCS	reactor coolant/cooling system
RO	reactor operator
ROP	Reactor Oversight Process
RRS	reactor regulating system
SCAQ	significant condition adverse to quality
SG	steam generator
SGTR	steam generator tube rupture
SIR	special inspection report
SPAR	Standardized Plant Analysis Risk
SPAR-H	The Standardized Plant Analysis Risk-Human Reliability Analysis
SRO	senior reactor operator
SS	shift supervisor
STA	shift technical advisor
TBV	turbine bypass valve
THERP	Technique for Human Error Rate Prediction
TNS	time not specified
TSC	Technical Support Center
W	Westinghouse (PWR)
XHE	human fault (HERA subevent code)
XEQ	equipment failure (HERA subevent code)

1 INTRODUCTION

1.1 Introduction

The Human Event Repository and Analysis (HERA) system provides a comprehensive taxonomy for human performance, with a particular emphasis on those factors that shape human performance at nuclear power plants with focus on human reliability analysis (HRA). HERA serves as a framework for cataloging human performance, providing a worksheet based classification scheme for coding human performance and a database for storing and trending findings across multiple data sources.

In the previous volume (NUREG/CR-6903, Volume 1, 2006), we provided an overview of HERA and its data structures. The present volume complements this discussion by providing guidance on how to code human performance using the HERA worksheets. Our discussion focuses on extracting aspects of human performance from two data sources—event reports and control room simulator studies. Moreover, our discussion largely highlights coding with respect to the worksheets, which are paper-based (see Appendices A and B) or are available electronically from the NRC program manager in charge of HERA or the authors of this report.

The goal of this report is to provide sufficient guidance to allow new groups of coders to utilize HERA as a tool for recording human performance. HERA provides an opportunity to capture a uniquely comprehensive snapshot of human performance across events and simulator studies. These data sources are not exhaustive, nor have all opportunities for capturing data from these sources been achieved. This volume enables new groups of coders to harness the HERA framework. It is through these multiple coding efforts that HERA will become a resource that allows analysts to review and perform analysis of human performance in way that facilitates identification of factors of interest in particular circumstances. In thus identifying those factors, it becomes possible to develop ideas for mitigating the effects of negative factors on human performance.

The present volume also contains a chapter on quality assurance (QA) processes for HERA data coding. A vetted process for coding helps ensure the reliability and validity of the data ultimately input into HERA. The QA process for HERA provides a guidance across the coding process, from initial training, to timeline generation, to verifying the assignment of performance shaping factors (PSFs).

1.2 Structure of This Report

The structure of this report is as follows:

1. Chapter 2 provides the primary coding instructions for extracting HERA data from event reports. This chapter includes relevant definitions to understand the various data fields and coding requirements in the HERA worksheets.
2. Chapter 3 outlines the process for coding HERA analyses from control room simulator studies. Such studies offer greater control over data collection than do event reports, but there are important considerations in terms of designing the study to meet specific HERA data coding requirements. Therefore, this chapter provides guidance both on designing the study to meet data requirements and on extracting and aggregating those data once the studies have been run.

3. Chapter 4 details the HERA QA process, offering practicable suggestions for ensuring quality coding of data in HERA.

In addition, the appendices provide the current HERA worksheets (Appendices A and B), reference information to assist in coding (Appendix C), a reference glossary for terms used throughout this report (Appendix D), and discussion of changes to the HERA structure made subsequent to publication of HERA NUREG/CR-6903, Volume 1 (Appendix E).

2 CODING INSTRUCTIONS

2.1 Introduction

This chapter provides detailed instructions for coding an event using the HERA taxonomy and definitions. This chapter represents guidance for using the HERA methods and represents the expected coding process. The instructions assume a typical analysis cycle and coding process following the methods developed and a mixture of skills and personnel. Because of limitations in personnel availability as well as time constraints, a shortened or compressed coding cycle may be employed. The instructions in this chapter apply to the analysis of event reports and simulator studies; however, when using simulator reports, further guidance is needed. Chapter 3 discusses the use of simulator data in HERA, and Chapter 4 provides guidance for employing a compressed analysis cycle.

2.2 Coding Team

HERA coding requires various types of knowledge and expertise; human factors (HF), HRA, and operations experience are required because of the interpretations made when analyzing an event. Rarely are these capabilities found in a single person, and experience to date demonstrates that coding an event is best performed by having more than one person interpret the same event. Therefore, at a minimum, two people should be employed for the HERA analysis process. Typically this includes an analyst with human factors and HRA experience and an analyst with operations experience. Even if a single analyst has all the required skills, a second analyst is necessary, because the quality assurance process relies upon the collaboration between two analysts. Beyond the two required analysts, additional team members may be enlisted as needed and may include reviewers and checkers. The instructions that follow will assume a two-person analysis team (an HF/HRA analyst and an operations analyst), but the process can be adapted to other team configurations. See Chapter 4 (Quality Assurance) for more on ensuring the quality of coding.

Specific skill sets necessary for the HERA coding process are:

HF and HRA

- Knowledge of human performance fundamentals (e.g., human cognition, PSFs, and organizational influences on behavior)
- Knowledge of HF issues as they relate to the design and operation of nuclear power facilities
- Knowledge of HRA theory and methods and an understanding of how HRA fits into the PRA process
- Experience with and a basic understanding of nuclear power plant operating experience and event reports
- Basic understanding of plant physics, chemistry, thermal-hydraulics, and nuclear engineering is very helpful

Operations (OPS) and PRA

- Knowledge of nuclear power plant systems, equipment, function, procedures, and operation (e.g., a former operator, NRC inspector, etc.)
- Knowledge of PRA and an understanding of how HRA fits into the PRA process.

2.3 Coding Process

2.3.1 Selection of Data Source

Selection of which events to code is largely outside the scope of this document. See HERA NUREG/CR-6903, Volume 1 for a discussion of the selection of data sources. Previous events have been selected for coding because they met certain criteria, such as being a report of an initiating event or a common cause failure. All events coded into HERA reflect human performance considerations, positive or negative. Whatever the basis for selecting an event to code, this chapter provides instructions on how the event is to be analyzed and data entered into HERA. Typical sources are Licensee Event Reports (LERs), Augmented Inspection Team (AIT) reports, and inspection reports (IRs). Other sources that have been used include root cause analysis (RCA) reports, Accident Sequence Precursor (ASP) analysis reports, other incident investigation reports, and simulator study reports.

Licensee event reports are written by the licensee when an event occurs that meets reporting requirements as defined in 10 CFR 50.72 and 50.73 (US NRC, 2000a), such as a plant shutdown required by technical specifications, operation or condition prohibited by technical specifications, a degraded or unanalyzed condition, safety system actuation, or an event or condition that could have prevented fulfillment of a safety function. LERs tend to be short and provide minimal information about one event, typically limited to what happened and when. Information about contributing factors to human performance is sparse. Past HERA analyses utilized LERs as the primary source, but the lack of detail makes LERs less valuable for extracting human performance insights as a primary source. It is recommended that LERs not be the sole source of a HERA analysis, particularly if the goal is a thorough understanding of an event from a human performance perspective.

Inspection reports are written by NRC inspectors according to the guidelines of the Reactor Oversight Process (ROP; US NRC, 2000b). There are a variety of types of inspection reports: the base, quarterly inspection report, which often covers a variety of issues at a plant; Special Inspection reports (SIRs); and AIT reports. If an incident at a plant merits further attention, as determined by the NRC Incident Investigation Program (US NRC, 2001) on the basis of deterministic criteria and risk significance, the NRC may charter a Special or Augmented Inspection Team. Special Inspection reports and AIT reports are typically more detailed, and usually have more information about contributors to human performance. While such reports take more time to analyze, it is recommended that SIRs and AIT reports be prioritized as source documents when available, because of the quality and quantity of information.

Root cause analysis reports have also been used in HERA coding, and they are usually rich in information about contributing factors to human performance. Typically, they are written by the licensee involved in an event, or by a contractor or consultant hired by the licensee. Such reports are useful source documents for HERA coding.

ASP Analysis reports typically focus on hypothetical modeling. The first several pages contain an event summary and the calculated Conditional Core Damage Probability (CCDP) or delta (Δ) CDP, which provides the risk of core damage associated with the event. The event summary is typically at the level of detail of a LER. An ASP analysis is a good addition to a set of source documents for an event, as it identifies the risk-significance of the event, but it typically does not provide enough detail on its own to be the primary source.

Root cause analyses and IRs offer considerably more detail than LERs, and typically provide more information that is of interest to HERA. It is recommended that as much information be collected for each event as possible, to enable a thorough event analysis.

Simulator study reports can be a rich source of human performance information and provide valuable information for HERA analysis. However, differences between simulator studies and event reports warrant a slightly modified approach when using simulator reports as a source for HERA coding. Chapter 3 discusses the use of simulator data in HERA in greater detail.

2.3.2 Process Overview

The coding process and the quality assurance processes are intertwined. This chapter explains the coding process, with instructions to analyst(s), but it is important to be aware of how coding fits into the overall quality process (see Chapter 4, Quality Assurance).

Specific steps in the coding process are listed below. Each step will be discussed in detail in the following sections.

1. Event review
2. Timeline generation and subevent breakdown
3. Worksheet A coding
    a. Event identifying information and summary
    b. Subevent code assignment
    c. Selection of subevents to receive Worksheet B coding
    d. Selection of subevents to be included in the graphical timeline
    e. Clustering
    f. Trends and Lessons Learned
    g. Subevent dependency
4. Worksheet B coding
5. External review
6. Clerical check
7. Submission to HERA database

2.3.3 Event Review and Timeline Generation

An event refers to the overall series of related individual successes and failures that leads to a reportable occurrence at a plant. This definition is somewhat broader than prescribed in 10 CFR § 50.73 (a)(2)(iv)(B), which describes specific reportable plant upset conditions (US NRC, 2000a). In HERA, an event comprises all activities and operations that influenced this occurrence, which include the entire chronology of significant human actions and plant operations contained in the source. An event typically consists of subevents, which are any subset of actions that were a part of or contributed to the overall event. A subevent may precede, include, or follow the actions that led to the reportable occurrence. Selected human subevents have separate analysis sections in Worksheet B.

Once an event is selected for HERA coding, the first step is to gather all associated documents (e.g., LER(s), IR(s)) and begin the event review. Depending on the event, there may be one or more source documents. For example, it is common for an event analysis to include a LER and a SIR or AIT report. Both analysts should read all source documents thoroughly to develop a full understanding of the event. It is recommended that the analysts highlight or otherwise take note of important human actions, errors, equipment failures and actuations, and other important subevents while they are reviewing the event report.

Before further specific instructions are given, it is necessary to provide some guidance on what makes a subevent important enough to be included in the event timeline (see Chapter 3 for a discussion of subevent breakdown when analyzing simulator studies). Most event sources will include only information related to the event under analysis, but this will not always be the case. For example, routine IRs will often include information about multiple unrelated issues, some of which may have nothing to do with the event in question. In a HERA analysis, the event timeline should include only subevents that are related to the overall event, meaning that they *contributed to* or *were a part of* the event sequence, both prior to and during the event. As discussed below, the analysts should work from the level of detail provided in the source documents when developing the event timeline. More importantly, the analysts should focus on issues that are of interest to HRA (e.g., things that make human failure or successes more or less likely, issues that contribute to improved or degraded human performance, things that make consequences of actions more or less severe, actions that lead to recovery of equipment or an error, issues that make recovery difficult, etc.). The analysts should endeavor to include as much detail as possible in the timeline, but should not include things that are irrelevant to the event progression or do not contribute to a thorough understanding of the event.

Once both analysts have reviewed the source material, the analysts should develop the event timeline together. For short or uncomplicated events (often with events that have only one LER as a source), generating the timeline should be simple. For long or complicated events, it may be easier for one analyst to draft a preliminary timeline for the event, which both analysts then refine together.

The first step in generating the timeline is to list everything that happened in the event in chronological order. Document all positive, negative, and neutral human actions, equipment failures and activations, important plant states, any external events that affect the plant or plant personnel, and everything else that the source provides as part of the event sequence, in as much detail as the source allows. At this point, the analysts should be focused on telling the event *story*; i.e., what happened during the event, who did what, from start to finish. Subevent identification is performed before subevent code assignment (see section 2.3.4.4), to refine the timeline into discrete subevents before deciding how the subevents are labeled. See Table 2.1 for an illustration of a partial preliminary event timeline. Some issues to be aware of during timeline generation include:

- Most data sources do not necessarily document human performance or human-system interaction chronologically. Therefore, this step usually requires extracting information from different places throughout the source document(s) and placing it into chronological order.
- Some sources, such as LERs, will have little detail. Other sources, such as AIT reports or SIRs, will be extensively detailed. Regardless of the amount of detail in the source, list all the subevents in as much detail as the source allows.

Table 2.1 Example of a Partial Preliminary Event Timeline

Date	Time	Description
2/15	1917	Steam generator tube rupture. #24 SG main steam line high radiation alarm, R-45 condenser steam jet air ejector (SJAE) high radiation alarm. Pressurizer level decreased; R-61D and R-55D monitors indicate substantial leak from reactor coolant system (RCS) to steam system.
2/15	1917	The R-45 detector response caused the SJAE discharge to divert to containment.
2/15	1917-1922	Operators entered AOI-1.2, "SG Tube Leak" and started a second charging pump. Operators closed all SG blowdown valves.
2/15	1929	ALERT event classification was declared based on an RCS leak > capacity of one charging pump, Emergency Action Level (EAL) 3.1.2.
2/15	1929	Security personnel failed to secure Unit 3 access gate, resulting in delays in accounting for all personnel.
2/15	1930	SG tube leak exceeded the capacity of 2 charging pumps.
2/15	1930	Operators manually tripped the reactor (entered E-0, "Reactor Trip/Safety Injection"). Entered TS 3.1.F.2.a(1) for primary-to-secondary leakage > 0.3 gpm, which required the reactor to be in cold shutdown within 24 hours. The licensee's post event analysis determined that the SG tube leak rate was approximately 146 gpm at this time.
2/15	1935-1941	Received high SG feedwater flow alarms. #24 SG level continued increasing due to the SG tube leak and auxiliary feedwater (AFW) injection.
2/15	1935-1941	Operators manually tripped both main feed pumps per ES-0.1, "Reactor Trip Response". Secured AFW feeding #24 SG to reduce #24 SG level. Began notifying state and local officials of ALERT (Form 30a).
2/15	1949	Emergency Response Pagers activated by corporate information group, at an excessive (20-minute) delay. This contributed to a delay in activating emergency operations personnel and facilities.
2/15	1959	Failure of licensee to account for all personnel within 30 minutes of Alert declaration.
2/15	2007	Notified NRC operations center of SG tube leak event, reactor trip, and ALERT per 10 CFR 50.72
2/15	2012	#24 SG narrow range level = 12% and lowering slowly. Resumed AFW flow to control #24 SG level. #24 SG level and pressure began rising.
2/15	2018	Began #24 SG isolation per AOI-1.2.
2/15	2019	Operators manually raised the #24 SG atmospheric steam dump valve (ASDV) lift setpoint to 1030 psig per AOI-1.2. This reduced the likelihood of a radiological release via the #24 SG ASDV.
2/15	2024	Secured AFW to #24 SG to reduce SG level. Charging pump suction shifted to refueling water storage tank to provide large inventory of borated water for RCS.
2/15	2029	Emergency Operations Facility (EOF), Operations Support Center (OSC), and Technical Support Center (TSC) not activated in required time (1 hour post Alert declaration).

- Use of a large white board or chalkboard, or listing out the subevents on paper is helpful for less detailed sources. For sources that are extensive or detailed, using a word processor or spreadsheet is often more useful, as it allows subevents to be more easily edited and rearranged as additional details are revealed in data sources.
- AIT reports or SIRs will often include a timeline of the event progression. LERs will occasionally include a timeline as well. Such a timeline is a valuable place to start, but it should not be considered complete or thorough enough for a HERA analysis. Often these timelines include things that happened during the immediate event response, but will leave out important latent errors or organizational weaknesses, as these types of reports have been written for a different purpose than HERA coding. The analysts should explore the remainder of the report thoroughly to account for all relevant subevents.

- It is common to find vague temporal statements such as “During the previous refueling outage…” or “In 1998…” in source documents, or to have discussion of a latent error that happened sometime before the event, with no mention of the date or even the year. If the source is not specific about the time frame of a subevent, the analysts should do their best to place the subevent in approximately the appropriate time in the timeline. Knowledge of plant operations usually is very helpful in this situation.

2.3.3.1 HERA Subevent Codes

Subevent code assignment does not take place until later in the timeline development. At this stage in the coding, the goal is to break down the event into subevents in detail, identifying discrete statements about what happened when and who did what. Applying the HERA subevent codes occurs after the sequence of subevents is finalized. Nevertheless, it is recommended that the analysts have the definition of the HERA subevent codes in mind as the timeline is generated, as this will be helpful in distinguishing separate subevents.

Before the subevent codes are discussed further, it is necessary to provide clarification of the terminology used in HERA. The previous volume of HERA used the terms “human error” and “XHE” interchangeably. The term “human error” is defined from a human-centered perspective and has a broad connotation, however, and as such, there is the potential for confusion about the use of these terms in HERA. Therefore, it is important to clarify that the two terms are not equivalent. It is also necessary to clarify the difference between “human failure event (HFE)”, a term used in HRA, and “human error” and “XHE” as used in HERA and this report.

The term “human error” has been defined from a human-centered perspective: generally, human error occurs when the planned action or sequence of actions fails to achieve the intended results, when the failure cannot be attributed to chance (Reason, 1990). Any discrepancy between the steps of human information processing (e.g., detection, interpretation, planning, and action; see section 2.3.5.6 below) or between the situation and detection is an error. For example, if an operator does not detect a situation, this represents a detection error. Slips (e.g., unintentionally pressing the wrong button; see section 2.3.5.7 below) is an outcome of inconsistency between planning and action.

The term XHE is defined from a *plant-centered* perspective, and is better characterized as a human fault. Any operator’s response that causes or will cause a negative effect on the plant, based on current plant state, is a human fault. As defined below, in order for a human action to be classified as an XHE, it must occur within a set boundary, be unsafe for the plant or personnel, have a negative impact on the plant or plant equipment or systems, or be a circumvention with negative results.

The difference between human error and XHE (or human fault) is illustrated in Table 2.2. XHE (1) is typical: a human error causes negative effects on the plant. XHE (2) occurs when an operator’s current action is performed according to an erroneous preceding activity (e.g., an incorrect plan). Because the operator’s action is performed according to what has been planned, the action itself is not a human error, but a human fault (XHE). An HS (1) occurs when, for example, an operator unintentionally presses the wrong button, but the action turns out to be beneficial for the plant. Such a case is rare, and it may be better classified as CI. It will be much more common to see HS (4), typical correct recovery activity.

Table 2.2 Classification Between Human Error, XHE, and HS

Action Type	Negative Effect on Plant	Positive Effect on Plant
Human Error	XHE (1)	HS (1)
Not a Human Error	XHE (2)	HS (2)

A Human Failure Event (HFE) is another term that can be confused with “human error” or “XHE”. HERA was designed to be a repository of data that would be useful for HRA, so the terms XHE and HFE are clearly related. Yet it is important not to confuse them. XHE is a term specific to HERA, with a specific definition, whereas HFE is a specific term used in HRA and PRA. Like XHE, a HFE will involve a human error, and it is defined from a *plant-centered* perspective. However, HFE is a specific term used in HRA. An HFE is a basic event that is modeled in the logic models of a probabilistic risk assessment (PRA; e.g., event and fault trees), and that represents a failure or unavailability of a component, system, or function that is caused by human inaction or inappropriate action. An HFE reflects the PRA systems’ modeling perspective (ATHEANA, 2000).

A key difference between the term XHE and HFE is the level of detail. As stated above, a HFE represents a basic event modeled in a PRA. In HERA, however, events are divided into subevents in as fine a level of detail as the source allows (see Section 2.3.3.2, Level of Granularity), which does not necessarily correspond to the level of detail associated with HFEs. Often, an activity that would be classified as one HFE in HRA would be separated into two or more XHEs in HERA. In other cases, it is possible that an action analyzed as an XHE in HERA may be equivalent to an HFE. Furthermore, HERA does not limit analysis of human behavior to activities modeled in HRA and PRA. Human performance that would not normally be modeled in HRA, such as a failure to update procedures, may be analyzed in HERA as an XHE.

HERA codes subevents to characterize the negative or positive effects of the subevents on the plant. These subevent codes are borrowed and adapted from the codes often used in PRAs. HERA employs seven subevent codes—three human subevent codes, three plant subevent codes, and one external subevent code—as depicted in Table 2.3 and explained in the next sections.

Table 2.3 HERA Subevent Codes

	Negative Outcome	**Positive Outcome**	**Context**
Human	**XHE**	**HS**	**CI**
Plant	**XEQ**	**EQA**	**PS**
External	**EE**	**EE**	**EE**

Human Subevents

XHE—represents a human fault (see discussion above) that has or potentially has a negative effect on the event progression. An XHE is a human action or inaction that:

- Occurs within the boundary of the nuclear steam supply system (NSSS) and balance of plant (BOP) systems; AND
- Is unsafe; OR
- Negatively or potentially negatively affects plant, system, equipment availability, and/or operability, or has negative consequences; OR
- Represents a circumvention with negative impact.

HS—represents a successful human action that has or potentially has a positive effect on the event outcome. HS is a human action that:

- Occurs within the boundary of the NSSS and BOP systems; AND
- Positively or potentially positively affects plant, system, equipment availability, and/or operability, or has positive consequences; OR
- Represents a successful recovery action; OR
- Represents a circumvention with positive impact.

CI—represents contextual information (CI) about the human action or inaction. It is any human action or inaction that does not meet the classification criteria for an XHE or HS. Specifically, CI represents human activity or information that:

- Is associated with design errors or improper guidance; OR
- Takes place outside the NSSS and BOP systems; OR
- Is an engineering function including onsite engineering; OR
- Represents background or contextual information about the human activity in response to the situation; OR
- Encompasses conversations and notifications.

Also, contextual information may include any information that affects the quality of the human action or interaction with the plant or its systems and components, or helps to clarify motivations, intentions, or decisions of the personnel involved in the event.

Some common examples of information that should be considered CI include:

- Notifications or communication with the NRC, such as relevant generic letters or requests for information
- Industry notices that are relevant to the event in question
- Changes in or descriptions of management practices or policies
- Descriptions of commonly held beliefs or biases that provide explanation for crew actions

See CI 6 through CI 10 in Figure 2.1 for additional examples of CI.

Note: While human activities that occur outside the established boundary (such as engineering and management functions) are normally considered CI, they may, at the analyst's discretion, be considered as XHE or HS if they are significant contributors to the event, or if they have significant consequences to plant equipment or people who are inside the NSSS and BOP systems. For example, in one risk-significant event, management and engineering at one plant repeatedly violated NRC regulations and their own maintenance and corrective action programs, which resulted in damage to the reactor vessel head and a loss of the design basis structural/pressure retaining boundary for the reactor vessel head. Because those management and engineering activities significantly contributed to the event and had significant consequences for systems within the boundary, they were classified as XHEs rather than CIs.

Plant and External Subevents

XEQ—represents an equipment (EQ) failure (X). Any instance of a piece of equipment or system or component not operating or activating as designed is an equipment failure and is coded as an XEQ.

EQA—represents successful automatic equipment (EQ) actuation (A) that has or potentially has a positive effect on the event outcome. Any instance of a piece of equipment or system or component automatically actuating as designed, without human interference, is coded as an EQA. This includes automatic trips.

PS—represents information about the plant state (PS) that helps to explain the event evolution, including, for instance, status of plant parameters at a given time, status of equipment that is neither a failure nor actuation, status of other equipment that is not significant to the event itself but informative from the standpoint of understanding what happened and when, or other noteworthy factors pertaining to plant status during the event.

EE—represents events external to the plant such as extreme weather, external fires, seismic events, or transmission system events.

2.3.3.2 Level of Granularity in Subevent Breakdown

A key issue during the subevent breakdown is the level of granularity: how finely to divide the event into subevents, or how narrow to focus the level of analysis. The analysts should endeavor to not focus too narrowly or too globally, and to remain as objective as possible. However, some amount of judgment or inference is frequently required. To aid analysts in this process, here are some questions and guidance they should consider while breaking down the event into subevents.

Analysts should begin with the level of detail provided by the source. Do not insert details into the timeline that are not a part of the source, unless there is a clear reason to do so. For example, if the source document omits describing a step in an action sequence that is necessary for stabilizing the plant after a reactor trip, it is acceptable for that detail to be inserted into the timeline if the analyst with operations experience can confirm that it had to occur and was merely omitted from the event report. Operations experience is key in situations such as this to interpret what was actually going on during the event.

Other questions to consider regarding level of granularity during subevent breakdown:
- Is the action being performed by a different person and/or crew than another action?
- Is there a separate purpose or goal for this action than a different action?
- Does it involve different equipment/system or a different task?
- Are there different consequences for the actions?

If the answer to any of these questions is yes, then the action generally should be coded as a separate subevent. If the answer is no, then the action should not be coded as a separate subevent. For example, setting the coolant flow rate would be coded as a subevent, but all the other actions associated with it, such as turning the valve or checking the setpoint indicator would not be broken down separately, as those actions have the same goal of setting the coolant flow rate.

Generally, analysts should break down human subevents into more detail than equipment subevents, primarily because HERA is focused on the study of human actions. Equipment activations that occur closely together can be combined into one subevent, but analysts should distinguish between failures and activations. For example, if a feedwater pump fails, triggering an automatic turbine trip and automatic reactor scram, the analyst would list the pump failure as a separate subevent and combine the turbine trip and the scram together in another subevent. If human actions occur between equipment failures or activations, the coder should show that on the timeline and not lump equipment subevents together that are separated by human actions.

Three crucial pieces of information characterize the subevents in terms of their contribution to the overall progression of an event:

- The timeline serves to detail the *proper sequencing of subevents*. An LER or other information source will typically contain the times and dates for at least some of the subevents. For this reason, the listing of subevents is referred to as the event timeline in HERA. This chronological information is especially useful for identifying fault or error precursors, for determining dependencies between subevents, and identifying recovery opportunities and actions.
- The event timeline contains a brief *narrative description of the subevents*. This description should provide adequate information so that subsequent users of HERA will not have to read the source information to understand what happened.
- The event timeline contains information about the *positive or negative effect of the subevent*. A subevent may have a negative effect—such as those factors that led to the reportable event—or a positive effect—such as corrective actions taken to remedy the fault, and recovery actions taken to bring the plant back into desired status.

Once the analysts have decided on the number of subevents and their order in the timeline, the timeline may be entered into HERA Worksheet A.

2.3.4 Instructions for HERA Worksheet A

There are minor differences between the HERA worksheets and the input fields in the HERA database, but these are differences in format rather than content or function. Where applicable, this manual will provide instructions for both users of the HERA database and users of the worksheets. Worksheets A and B are provided in Appendices A and B of this report. Electronic versions of the HERA worksheets may be obtained from the NRC program manager in charge of HERA or through the HERA development team at INL.

Note: It is advised that the analysts be as detailed as possible in the Worksheet A coding. This is the bulk of the work for processing an event, and the more thorough and detailed the information in Worksheet A, the more efficiently Worksheet B coding is completed. For example, if there are detailed comments in the Index of Subevents describing PSFs, other subevents that contributed to a particular subevent, coding the subevent with Worksheet B is easier and faster.

2.3.4.1 Coder/Reviewer Table

This table serves two purposes. First, it documents who was involved in analyzing an event, and secondly, it documents when the event was coded. This is particularly important for keeping track of what version of HERA was used to code an event. Each analyst and reviewer should enter his or her initials and the date he or she completed his or her analysis or review.

2.3.4.2 Section 1: Plant and Event Overview

This section provides plant and event identifying information.

1. *Item 1. Primary Source Document*: The purpose of this field is to provide the HERA user with a reference to the source information. Enter into this field the identifying document information for the source of the event being coded. If a LER is the source, enter the plant docket number (three-digit number that identifies the plant and the unit) followed by the LER number (which identifies the year and LER report number, e.g., 2000-001-00). If an inspection report is the source, enter the report number. In some cases, more than one source will be used. For example, HERA analyses often include an AIT report, one or more LERs, and perhaps one or more IRs. In such cases, enter the document number for the primary source into this field (i.e., the source from which most of the information being coded is derived typically because it contains the most detail).
2. *Item 2. Other Source Documents*: If there is more than one source of information for an event, such as in the example provided above, enter all other document numbers into this field.
3. *Item 3. Plant Name*: Enter the full name of the plant where the event occurred. Include the unit number(s) involved.
4. *Item 4. Plant Type*: This field is used to indicate the plant type. U.S. nuclear plants are either pressurized water reactors (PWRs) or boiling water reactors (BWRs). If this information is not available in the source documents, the analyst with operations experience should be able to locate it. An “Other” field is included in the database to allow for coding events at other types of plants, such as simulators, research reactors, or reactors from other countries.
5. *Item 5. Plant Operating Mode and Power Level*: The information for these two fields is on the front page of every LER, or usually can be found within the text of an inspection report. Plant Operating Mode is often indicated in numbers (e.g., Mode 1). If the coder wishes, a description can be added in the field (e.g., Mode 1, power ascension). Enter the power level into the next field.
6. *Item 6. Event Information*: This section documents the event basics: date, time, type, and a high-level summary.
    a. Event Type: Indicate whether the event was an initiating event, and whether a common cause failure was involved. Check Yes or No for each. An event is an initiating event if an automatic or manual reactor scram occurred, or if there was automatic or manual actuation of any engineered safety features. An event is considered common cause if a failure of two or more components or human actions during a single short period of time are a result of a single shared cause.
    b. Event Date/Time: Enter the date and time of the event, if available. This information should be on the front page of a LER or within the event description

of an inspection or RCA report. An event can span across a long period of time, but this item collects information on the date and time of the initiating event, or the time of discovery of a reportable condition. If the event under analysis is a simulator exercise, enter the date and time that the exercise took place. If there is no information available to indicate date and/or time of the event, leave this field blank.

c. Event Description: This should be a one- to two-sentence high level description of the event under analysis.

7. *Item 7: Affected Function:* To measure plant performance, the NRC oversight program focuses on seven specific "cornerstones" and three "cross-cutting" areas (see Appendix C for detail). In HERA, these cornerstones and cross-cutting areas are the major functions assessed in this field. A list of these functions and descriptions are included in Appendix C. The information necessary to select the proper function can usually be found in the body of an inspection report. The analyst with operations experience should be able to assist in making this determination if the information is not readily available in the source documents. In the database, this information is provided in a drop-down list, and the analysts should select all that apply. If no function was affected, select "Not Applicable".

8. *Items 8-9: System and Component:* The information for these two items can usually be found in the Component Failure section or Event Analysis section of a LER, and in the text of an inspection report. Source documents vary in level of detail, so it is possible that information necessary for these items is buried in the text of the event report. The analyst with operations experience should be able to identify the necessary information for these items if it is not easily found in the source document(s). Based on the selection of Plant Type, a drop-down menu of the major systems and components will be provided, with an "Other" option and corresponding input field. See Appendix C for a detailed list of systems, and components for the two U.S. plant types. If no system or component was affected, select "None" or "Not Applicable".
   a. *Affected System(s)*: Identify the system(s) affected during the event, whether a loss of system availability or operability occurred or not. Include system(s) that could have been affected during the event, even if they operated successfully.
   b. *Affected Component(s)*: If there is sufficient information available in the source document(s), identify the specific components affected during the event, whether a loss of availability/operability occurred or not. Include component(s) that could have been affected during the event, even if they operated successfully.

9. *Item 10. Source*: This item allows the analysts to document the type of report used as the primary source. For events with multiple source documents, select all that apply.
   a. LER
   b. ASP analysis: Some events will have already gone through an ASP analysis. If an ASP analysis is included in the source documents, check the appropriate box and indicate the Conditional Core Damage Probability (CCDP) or ΔCDP assigned by the ASP analysis. Some inspection reports also may include CCDP or ΔCDP information. If this is the case, enter the CCDP or ΔCDP value in the appropriate field but leave the ASP analysis checkbox blank.
   c. AIT Report
   d. Other: If the source document(s) other than a LER or AIT, for example, an IR, a SIR, or an RCA, are included in the event analysis, check this field and enter the type of report in the text input field.
   e. Simulator Study: This option allows results from simulator studies to be analyzed by the HERA process. Include simulation/experiment description and identifying

information here. See Chapter 3 for further instructions when analyzing a simulator report.

i. Experiment Information: Enter a brief description of the overall simulator study under investigation (e.g., "SGTR Complexity Study").
ii. Scenario: Enter information about the experimental manipulations. For example, the overall study might feature two scenarios corresponding to the independent variables that are manipulated (e.g., "Basic SGTR" vs. "Complex SGTR").
iii. Variant: This field is used to describe further variations of the scenarios. For example, a "Complex SGTR" scenario might include additional variants of "Clear Indicators" vs. "Misleading Indicators".
iv. Crew: Enter information about which crew(s) correspond to each scenario and variant.

10. *Item 11. Similar to other events*: If in the source documents this event is stated to be, or otherwise the event is known to be similar to other events by the analysts, check "Yes" and provide explanation in the text field. In making this decision, analysts may want to consider whether other events involved the same or similar initiating event, equipment failure(s), human error(s), or complications. This allows users to identify situations where lessons learned from one event might not have been applied at other plants, for example, or to identify situations that might be relevant industry-wide.

2.3.4.3 Section 2: Event Summary

Enter into this field a summary of the event. In most cases, copying the report abstract is a good place to start, but the analysts should discuss aspects of the event that are important from an HRA perspective. This normally includes PSFs that were prevalent during the event, such as work processes or procedures. This summary should provide the reader with a good general understanding of what happened during the event and what factors contributed to human performance. For simulator studies, this section should detail the essential information of the simulator study. See Chapter 3 for further guidance.

2.3.4.4 Section 3: Index of Subevents

Analysts enter the subevent timeline they have generated into the Index of Subevents. Analysts who are using the HERA worksheets should use additional pages as necessary or contact the NRC HERA project manager or the INL HERA development team for electronic versions of the worksheets.

1. *Subevent Code*: At this point in the coding process, the analysts assign HERA subevent codes to each subevent in the timeline. Here, they enter the subevent code, followed by a numerical identifier (e.g., XHE 1, XHE 2, HS 1, PS 1…). Each type of subevent is independently and sequentially numbered. For example, all the XHEs are numbered consecutively from XHE 1 to XHE n; all the HSs are numbered consecutively from HS 1 to HS n, as are the EQAs, XEQs, CIs, and PSs. Each subevent is uniquely identified as a result. Use the definitions from section 2.3.3.1 as a guide.
2. *Date*: Enter the date of each subevent. If the source only provides a vague date such as "1998" for a subevent, enter that information here. If no date is specified, enter "DNS" (date not specified). If the date is approximate, check the "Approximate" box.

Table 2.4 Human Factors Information System (HFIS) Work Type Code and Definitions

Code	Definition
O	Operations (Control Room): control room activities by operations department personnel, including monitoring of displays and phone notification to NRC
B	Operations (Balance of Plant): any work performed in the field by a member of the operations department, either licensed or non-licensed
M	Maintenance/repair: any work performed by either electrical, mechanical, or I&C personnel related to maintenance or repair of equipment
T	Testing: any work performed, regardless of department, for the purpose of testing a system or component
S	Surveillance: any work performed, regardless of department, that is specifically related to ensuring or determining operability - usually related to Technical Specifications
C	Calibration: any work, usually performed by I&C technicians, related to ensuring that the data output of a measuring, metering, or detecting device is accurate
F	Modification: any work by any department specifically related to the installation of a modification to the plant
R	Refueling: any work by any department specifically related to the movement of fuel and any other activities occurring on the refueling floor
V	Troubleshooting: any work by any department specifically related to determining the cause of an equipment problem
H	Radiological protection: any work related to performing contamination surveys, decontamination activities, source control, or radiation worker activities
G	Design: any work done by engineering in their role as design or system engineers, (e.g., calculations or analyses)
P	Procedure development: any work by any department related to the development of guidance documents including procedures, directives or reference documents, tests, and calculations
K	Housekeeping: any work by any department related to maintaining an appropriate material condition in the plant, also includes cleaning activities
Q	Fire protection: any work related to stationary fire watches or fire watch rounds, includes fire brigade drills
A	Administrative: activities related to material procurement and distribution, manpower planning, staffing, work planning and scheduling, reporting or documentation (paper LERs), or log keeping
D	Drills: any activities related to the conduct of emergency drills or emergency planning
N	Training: any activities related to the training or qualification of personnel, including classroom as well as on-the-job training activities
W	Assessment: any type of assessment or evaluation activities, including causal analyses, corrective action program evaluations, self-assessments, Technical Specifications reviews, safety reviews (including industrial safety), and special reviews
Y	Shipping/transportation: any activities related to the shipping, transportation, or receiving of radioactive materials (e.g., fuel)
X	Site-wide: any activities that are related to or affects all work groups on site
Z	Other/unknown: any specifically identified activity that is not covered in the other definitions, or any activity not described in sufficient detail to assign to another work type

Table 2.5 HERA Personnel Codes for Worksheet A

O	**Operations**: includes all licensed operators, including reactor operator (RO) and senior reactor operator (SRO), regardless of position. This category also includes system specialists (SS), shift technical advisor (STA), non-licensed operators, rad-waste operators, auxiliary operators, plant equipment operators, fire department work planning, outage planning, and project management group. Use the higher level code if there is insufficient information to support using a more detailed code. Detailed codes in this category specific to use in HERA include: O-S: Operations Supervisors O-C: Control Room (CR) Operators O-A: Outside of CR Operators O-T: Technical Support Center (TSC)
M	**Maintenance and Testing**: includes all maintenance personnel, including electrical, mechanical, and instrumentation and control (I&C) technicians. Use the higher level code if there is insufficient information to support using a more detailed code. Detailed codes in this category specific to use in HERA include: M-S: Maintenance Supervision and/or Planning M-M: Mechanical maintenance technicians and personnel M-E: Electrical maintenance technicians and personnel M-I: I&C technicians and personnel
B	**Management**: includes all management personnel, including lower-level supervisory managers and all other higher-level management.
S	**Plant Support Personnel**: includes all departments and personnel who support plant operations, administration, training, security, and other functions external to the control room. Use the higher level code if there is insufficient information to support using a more detailed code. Detailed codes in this category specific to use in HERA include: S-A: Administrative Support S-C: Chemistry S-D: Emergency Planning/Response S-G: Engineering S-V: Fitness for Duty S-F: Fuel Handling S-H: Health Physics S-P: Procedure Writers S-Q: Quality Assurance (QA)/Oversight S-R: Security S-T: Training S-Y: Shipping/Transportation S-S: Specialized Task Force S-W: Work Control S-L: Licensing/Regulatory Affairs
X	**Site-Wide**: use when all work groups are involved
N	**Non-Plant Personnel**: includes all personnel not employed by the plant, including contractors, vendors, and NRC personnel. Use the higher level code if there is insufficient information to support using a more detailed code. Detailed codes in this category specific to use in HERA include: N-C: Contractor Personnel N-M: Manufacturer N-R: NRC/Regulator N-V: Vendor
Z	**Other**: use when none of the above categories apply or the work group cannot be determined from the available information. Provide an explanation in the corresponding text field.

3. *Time*: Enter the time of each subevent. If the time is not known, enter "TNS" (time not specified). If the time is approximate, check the "Approximate" box. Due to space limitations, the date and time fields are combined in the worksheets, and there is no "Approximate" box. Users of the worksheets are advised to use a "~" to indicate approximate dates or times.
4. *Work Type*: The codes used in this field were imported directly from Human Factors Information System (HFIS; US NRC, 2006). HFIS analyzes all suitable IRs and LERs to identify high-level human performance factors information, such as personnel involved, type of work, and contributing factors, in each event for the purpose of trending within and across plants. In HERA, the HFIS Work Type field is used only with human subevents, XHEs and HSs. HERA uses this field to describe the type of work being performed during the human subevent. See Table 2.4 for the code and definitions to use for this field.
5. *Personnel:* Identify the personnel involved in each human-related subevent (XHE, HS, and CI). This information is the same as the Personnel section in Worksheet B, but because not all human subevents receive Worksheet B coding, it is included here in Worksheet A to provide personnel information about subevents that do not receive Worksheet B coding. See Table 2.5 for personnel codes.
6. *Pre-Initiator, Initiator, Post-Initiator*: This column serves to indicate whether a subevent occurred before, during, or after an initiating event. HERA uses the definition of an initiating event as an automatic or manual reactor scram or engineered safety feature actuation. Besides post-initiator human actions, it is also important to track pre-initiator human actions, because they can often be the cause of an initiating event or otherwise contribute to the event evolution. Indicate in this field whether the human action occurred pre-initiator (PRE), during the initiating event (INIT), or after the initiator (POST). In instances where the event being coded does not involve an initiating event, all human subevents should be indicated as PRE.
7. *Latent/Active*: For XHEs only, indicate whether the error was active (A) or latent (L). HERA uses "Active" and "Latent" as indicators of delayed or immediate effect. If the effects of an error are immediately apparent, the XHE is "active." If the effects of an error do not immediately manifest, then the XHE is "latent."
8. *Omission/Commission*: For XHEs only, indicate whether the error was an error of omission (O), failure to take an action, or an error of commission (C), an incorrect action.
9. *Subevent Summary*: Enter a one- to two-sentence synopsis of the subevent. Because subevent descriptions can be long and detailed, this field provides a short summary statement for use in the graphical timeline. This field is not available on the worksheets due to space limitations. When using the worksheets, it is recommended that the first one or two sentences of the subevent description serve as the subevent summary.
10. *Subevent Description*: Enter the full, detailed description of each subevent.
11. *Human Action Category*: For XHEs and HSs, enter the action category (see Table 2.6).
12. *Recovery*: For human successes (HSs) only, indicate whether the subevent represents a recovery. A recovery is a human action performed to:
    - Regain equipment or system operability from a specific failure (or, in the case of EQAs, an automatic trip) or human error to mitigate; or
    - Reduce the consequences of the failure, trip, or error.
13. *Worksheet B*: Indicate whether the human subevent (XHE or HS) will receive Worksheet B coding. In making this determination, two decisions must be made for each subevent: whether the subevent contributes significantly to the event progression, and whether the subevent should be clustered with other subevents.

Table 2.6 HERA Human Action Category Codes

#	Generic XHEs	Examples of Errors
0	Other [none]	
1	Operator fails to change or incorrectly changes electrical lineup or instrumentation configuration in response to condition	Failure to transfer load to energized bus, or to open and close breakers as needed to restore power to bus
2	Operator fails to change or incorrectly changes valve lineup in response to condition	Plant condition occurs that requires different system lineup. Operator fails to react correctly
3	Operator fails to change or incorrectly changes ventilation line-up on condition	Failure to open equipment room doors or dampers after loss of power/ventilation
4	Operator fails to properly restore or incorrectly restores system/component after maintenance	EDG assumed to be operable but control switch is out of position, or restoration valve lineup incorrect
5	Maintenance personnel return miscalibrated/inoperative instrumentation, controls or components to service	Pressure/level/flow instruments not calibrated correctly, safety relief valves lift at wrong pressure, or maintenance incomplete or erroneous
6	Operator fails to diagnose or incorrectly diagnoses condition	Failure to determine cause of condenser vacuum decreasing while at power
7	Operator fails to properly change or incorrectly changes plant condition in response to condition or diagnosis	Failure to begin power reduction in response to a noted degradation of service water system performance
8	Operator fails to trip, control, or adjust reactor / active system or component on monitored condition indication or diagnosis, or does so incorrectly	During primary system cooldown, maximum cooldown rate is exceeded, or upper limit on oil temperature is exceed on reactor coolant pump shaft bearing
9	Operator fails to or incorrectly starts or maintains standby/inactive system / component at condition/set point or diagnosis	Failure to start RCIC (BWR) on low reactor level or failure to monitor EDG key parameters or exceeding a safety limit causes component unavailability
10	Operator fails to recover or incorrectly recovers component/system that has failed/was tripped	Failure to restart pumps or other loads on bus after being re-energized
11	Operator fails to bypass/clear trip signal as needed, or does so incorrectly	Condition causing trip has cleared, but component cannot be restarted because interlock is still active
12	Failure to resolve known deficiencies in equipment, procedures, or training of plant personnel, including using workarounds	Using manual control of steam pressure when an automatic pressure regulator is not operative for an extended period
13	Failure to follow administrative, procedural, or regulatory requirements	Improper staffing or scheduling of drills, configuration management failures, or poor log-keeping or shift turnover
14	Non-plant personnel cause plant / system / component to trip or operate incorrectly	System engineer disturbs wire label in terminal box, causing short and plant trip, or crafts person bumps relay cabinet with ladder, causing trip

Table 2.6 Continued

#	Generic HSs	Examples of Successes, Recoveries
0	Other [none]	
1	Operator correctly changes electrical lineup or instrumentation configuration in response to condition	Operator transfers load to energized bus, or opens and closes breakers as needed to restore power to bus
2	Operator correctly changes valve lineup in response to condition	Plant condition occurs that requires different system lineup. Operator reacts correctly
3	Operator correctly changes ventilation line-up on condition	Equipment room doors or dampers are success-fully opened after loss of power/ventilation
4	Operator correctly restores system / component after maintenance	EDG including control switch, is correctly restored to operation, or restoration valve lineup is correct
5	Maintenance personnel return properly calibrated/operative instrumentation, controls or components to service	Pressure/level/flow instruments are calibrated correctly, safety relief valves lift at correct pressure, or maintenance is complete and correct
6	Operator correctly diagnoses condition	Operators determine cause of condenser vacuum decreasing while at power
7	Operator correctly changes plant condition in response to condition or diagnosis	Operator correctly begins power reduction in response to a noted degradation of service water system performance
8	Operator correctly trips, controls, or adjusts reactor / active system or component on monitored condition indication or diagnosis	During primary system cooldown, maximum cooldown rate is not exceeded, or upper limit on oil temperature is not exceed on reactor coolant pump shaft bearing
9	Operator correctly starts or maintains standby/inactive system / component at condition/set point or diagnosis	Operator starts RCIC (BWR) on low reactor level or correctly monitors EDG key parameters or prevents exceeding a safety limit that would cause component unavailability
10	Operator correctly recovers component / system that has failed/was tripped	Successfully restarts pumps or other loads on bus after being re-energized
11	Operator correctly bypasses / clears trip signal as needed	Condition causing trip has cleared, and component can be restarted because interlock has been cleared by operator
12	Plant staff timely resolve known deficiencies in equipment, procedures, or training of plant personnel, avoiding the use of workarounds	Timely restoring a malfunctioning automatic pressure regulator, avoiding the use of manual control of steam pressure for an extended period
13	Proper adherence to administrative, procedural, or regulatory requirements	Proper staffing or scheduling of drills, accurate configuration management, or complete log-keeping or shift turnover
14	Non-plant personnel avoid or prevent causing plant/system/component trips or incorrect operation	System engineer investigates in-plant conditions without causing plant trip, or crafts person conducts sensitive work without causing trip

a. *Subevent Contribution*: A key issue to consider when determining whether the human subevent qualifies for Worksheet B analysis is whether the subevent contributes significantly to the event progression. Some ways that a subevent can contribute significantly to an event, both positively and negatively, include whether or not it:

- Affects system or component operability or availability, either by making equipment unavailable or by restoring equipment operability;
- Complicates response to the event or simplifies the situation by removing a complication;
- Distracts operators or requires operator attention to be diverted from the event, or it eliminates distractions;
- Adds to or eliminates confusion;
- Delays work that should be done immediately, or it involves completing necessary work quickly;
- Includes sufficient information in the data source for determination of appropriate assignments in Worksheet B;
- Represents a successful action that is beyond the routine, well-trained, normal job expectations.

Specific instructions include:

- If a human subevent does not warrant Worksheet B analysis on its own, analysts should consider whether the subevent should be included in a subevent cluster (13.b below), as it may be a part of a larger sequence of actions that together have a significant effect on the event progression. If the subevent is not part of a cluster, leave the Worksheet B checkbox blank and proceed to Item 14, Related Subevents.
- If a human subevent contributes significantly to the event progression, it should receive Worksheet B coding. Analysts should next consider whether the subevent should be included in a subevent cluster (13.b below). If the subevent is not part of a cluster, check the Worksheet B box and proceed to Item 14, Related Subevents.

b. *Subevent Clustering*: Although all types of subevents are to be included in the event timeline, only XHEs and HSs are included in the subsequent full HERA analysis utilizing the Part B Worksheets. Because human subevents may be closely related, it may be possible to combine them for Worksheet B analysis. Clustering subevents achieves coding efficiency by reducing the number of separate Part B Worksheets that must be completed for each event.

Only XHEs and HSs are eligible for clustering, and it is only allowable to combine subevents that are in the same category (e.g., XHE+XHE, HS+HS, but not XHE+HS). The analysts may combine multiple XHEs or HSs into one, when:

- They are a part of the same goal and strategy to achieve it, *AND*
- The same PSFs apply to all included subevents, *AND*
- There are no intervening influences to change the situation or context (e.g., no additional cues, unexpected occurrences, related condition changes, etc.), *AND*
- There are no separate subsequent effects of the included subevents.

If human events have the same goal, strategy, and context, then they may be combined for the purposes of Worksheet B coding. Each subevent in a cluster is still considered a separate subevent in the timeline, but the Worksheet B coding applies to all subevents in the cluster. Typically, combined XHEs or HSs might involve the same system, but they could represent different equipment with the same goal and strategy. Clustered subevents typically will follow a strict chronological sequence without intervening subevents, but it is possible for clusters to bridge subevents when parallel sequences of activities occur.

Common instances where clustering is appropriate include occasions where the same mistake is made repeatedly, or when a decision or plan results in several subsequent actions as part of or result of that plan. Clustering then serves as a means to combine those subevents together for Worksheet B coding.

For instance, as an example of clustering when the same mistake was made repeatedly, on seven occasions over sixteen years, a licensee was made aware that their auxiliary feedwater (AFW) system was not capable of performing its safety function under certain conditions, but the licensee repeatedly failed to identify the significant condition adverse to quality (SCAQ). The first six of those seven XHEs were clustered together, as they were all failures of the same goal, had the same PSFs, no intervening influences, and no separate downstream effects. However, the seventh instance of this same mistake was not included in the cluster, because a contractor identified a discrepancy in the Licensee's safety documents, providing a cue (an intervening influence) for the Licensee to recognize and correct the issue. The Licensee failed to do so; the associated XHE was not included in the previous cluster and received separate Worksheet B coding.

As an example of clustering subevents that are all part of the same plan, following an excessive cooldown after a reactor trip, operators erroneously decided to heat the RCS loop, which caused an undesirable increase in pressurizer level and pressure. As a result of this decision, operators had to take several steps, including manually increasing main spray to control the pressure increase and removing charging pumps from service to control the pressurizer level increase. Because these steps were part of the same strategy, had the same PSFs, no intervening influences, and all led to the same downstream consequence (an uncontrollable RCS pressure drop), they were clustered together.

Specific instructions for indicating clusters in Worksheet A include:

- When several subevents are clustered, the analysts indicate Worksheet B coding on the first subevent in the cluster, but not on the remaining subevents. In the Comments field for each subevent of the cluster, the analysts indicate that it is clustered and the subevents with which it is clustered. Each subevent is listed separately in the Index of Subevents, but the single Worksheet B coding applies to all subevents in that cluster.

14. *Related Subevents*: List all subevents that are related to the subevent in question, both prior to and after the subevent. This allows the analyst to show what subevents are connected to each other and to indicate possible cause and effect. For example, if an XHE causes a later XEQ, list the XEQ in the Related Subevents field for the XHE, and vice versa for the XEQ.

15. *Comments*: This field is used to make any comments about the subevent. This is useful for identifying clusters, explaining the source of dependency between subevents for use in the dependency table, for explaining PSFs that contributed to a subevent for use in Worksheet B coding, for providing background information about a subevent, for explaining any inferences made about the subevent, or for explaining why a human subevent will not be receiving Worksheet B coding. It is important that the analysts use this field as extensively as possible to facilitate a thorough event understanding by subsequent users of the data. Providing as much information as possible in this field can also enhance the ease and efficiency of subsequent Worksheet B coding.
16. *Graph*: Use this checkbox to indicate which subevents in the Index of Subevents should be included on the graphical timeline. The HERA database automatically generates a graphical timeline based on this checkbox. For short and simple events, all subevents might be included on the graphical timeline. However, for long or complicated events, including all the subevents would lead to a graphical timeline that is busy and difficult to read. Generally, the following subevents should be included on the graphical timeline:
    - All human subevents that receive Worksheet B coding
    - Key equipment failures and actuations that occur during the event progression
    - All CI subevents that are important to understanding the event progression
    - Key PS subevents that are important to understanding the event progression

    The analysts should work together to identify all the key subevents to include on the graphical timeline to present an appropriate visual summary of the event. Exceptions to the above guidance are left to the analysts' discretion.

Figure 2.1 below shows the completed Index of Subevents for the preliminary subevent timeline presented in Table 2.1.

2.3.4.5 Graphical Timeline

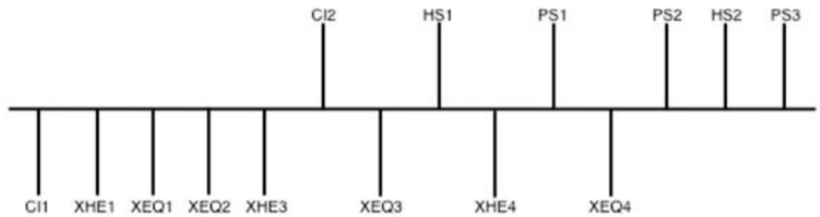
The HERA software database provides the capability to produce graphical timelines of the subevents selected for graphing. The graphical timeline affords a HERA user the ability to obtain a quick overview of the progression of the most important subevents throughout an event. Time is plotted along the horizontal axis, with positive and neutral subevents projecting upward from the axis and negative subevents projecting downward. The corresponding subevent summaries are presented below the timeline. Optionally, dependency may be included and is depicted as lines connecting subevents. Note that it is possible for the graphical timeline to be continued across multiple pages for those events that have a particularly detailed or extended chronology. The software necessary to generate the graphical timeline is not available with the worksheets. See Figure 2.2 for an example timeline.

2.3.4.6 Section 4: General Trends Across Subevents / Lessons Learned

1. *General Trends*: This section is used to illustrate any strong, overarching trend(s), issue(s), or context(s) across subevents. This section should be completed when an issue is seen repeatedly throughout the event, to highlight the trend that may not be readily evident from the separate Worksheet B coding. For example, if an event involves multiple instances of crew performing workarounds rather than fixing a problem, or if there is a cultural influence that affects all subevents, it could be documented and explained here.

Subevent Code	Date / Time	Work Type	Personnel	Pre / Initiator / Post	Latent / Active	Omission / Commission	Description	Human Action Category	Recovery	Worksheet B	Related Subevents	Comments	Graph
XEQ 1	2/15/00, 1917			INIT	A		Steam generator tube rupture. #24 SG main steam line high radiation alarm, R-45 condenser steam jet air ejector (SJAE) high radiation alarm. Pressurizer level decreased; R-61D and R-55D monitors indicate substantial leak from reactor coolant system (RCS) to steam system.		☐	☐			☒
EQA 1	2/15/00, 1917			POST	A		The R-45 detector response caused the SJAE discharge to divert to containment.		☐	☐			☐
HS 2	2/15/00, 1917-1922	O	O-C	POST	A		Operators entered AOI-1.2, "SG Tube Leak" and started a second charging pump. Operators closed all SG blowdown valves.	9	☐	☒		Human Action Category: Also #2.	☒
HS 3	2/15/00, 1929	O	O-S	POST	A		ALERT event classification was declared based on an RCS leak > capacity of one charging pump, Emergency Action Level (EAL) 3.1.2.	13	☐	☐		Does not directly contribute to the progression of the event; does not qualify for Worksheet B.	☐
CI 6	2/15/00, 1929	Z	S-R	POST	A		Security personnel failed to secure Unit 3 access gate, resulting in delays in accounting for all personnel. See CI 8, CI 14.		☐	☐	CI 4; CI 8, CI 14	Work Type Other (Z): Security This was not a procedural requirement , but security personnel were expected to immediately ensure that the gate was closed. This resulted in some ERO responders not being accounted for because they bypassed the main gate for this gate.	☐
PS 9	2/15/00, 1930			POST	A		SG tube leak exceeded the capacity of 2 charging pumps.		☐	☐			☐
HS 4	2/15/00, 1930	O	O-C	POST	A		Operators manually tripped the reactor (entered E-0, "Reactor Trip/Safety Injection"). Entered TS 3.1.F.2.a(1) for primary-to-secondary leakage > 0.3 gpm, which required the reactor to be in cold shutdown within 24 hours. The licensee's post event analysis determined that the SG tube leak rate was approximately 146 gpm at this time.	8	☐	☒		Cluster includes HS 5	☒
PS 10	2/15/00, 1935-1941			POST	A		Received high SG feedwater flow alarms. #24 SG level continued increasing due to the SG tube leak and auxiliary feedwater (AFW) injection.		☐	☐			☐
HS 5	2/15/00, 1935-1941	O	O-A	POST	A		Operators manually tripped both main feed pumps per ES-0.1, "Reactor Trip Response". Secured AFW feeding #24 SG to reduce #24 SG level. Began notifying state and local officials of ALERT (Form 30a).	7	☐	☐		Clustered with HS 4	☐
CI 7	2/15/00, 1949	D	S-D	POST	A		Emergency Response Pagers activated by corporate information group, at an excessive (20-minute) delay). This contributed to a delay in activating emergency operations personnel and facilities. See XHE 11.		☐	☐	XHE 11	The procedure and process used to activate the pagers were complex (they had to fill out a questionnaire for gathering facts about the event) and required an excessive period of time to activate the pagers. Additionally, the outgoing message was incorrect and they had to record a different message prior to sending out the signal.	☐
CI 8	2/15/00, 1959	D	S-D	POST	A		Failure of licensee to account for all personnel within 30 minutes of Alert declaration. See CI 6.		☐	☐	CI 6	There was an inconsistent understanding between ERO managers of the requirements for declaring that accountability was complete. Accountability procedures and training were inadequate. There was no procedure or related training describing the duties of security guards regarding how to allow access for the ERO personnel to respond to ERO facilities. As a result security personnel were uncertain as to where to send responders. Additionally, some responders were unfamiliar with where to report, attributed to CI 4.	☐
CI 9	2/15/00, 2007	O	O	POST	A		Notified NRC operations center of SG tube leak event, reactor trip, and ALERT per 10 CFR 50.72.		☐	☐			☐
CI 10	2/15/00, 2012	O	O-C	POST	A		#24 SG narrow range level = 12% and lowering slowly. Resumed AFW flow to control #24 SG level. #24 SG level and pressure began rising.		☐	☐			☐
HS 6	2/15/00, 2018	O	O-C	POST	A		Began #24 SG isolation per AOI-1.2.	7	☐	☒		Cluster includes HS 7 and HS 8	☒
HS 7	2/15/00, 2019	O	O-C	POST	A		Operators manually raised the #24 SG atmospheric steam dump valve (ASDV) lift setpoint to 1030 psig per AOI-1.2. This reduced the likelihood of a radiological release via the #24 SG ASDV.	8	☐	☐		Clustered with HS 6 and HS 8	☐
HS 8	2/15/00, 2024	O	O-C	POST	A		Secured AFW to #24 SG to reduce SG level. Charging pump suction shifted to refueling water storage tank to provide large inventory of borated water for RCS.	7	☐	☐		Clustered with HS 6 and HS 7	☐
XHE 11	2/15/00, 2029	D	S-D, O-T	POST	A	C	Emergency Operations Facility (EOF), Operations Support Center (OSC), and Technical Support Center (TSC) not activated in required time (1 hour post Alert declaration). See CI 6, CI 7, CI 8.	13	☐	☐	CI 6, CI 7, CI 8	Quality of support had more of an impact than the lateness of support; this subevent not coded on Worksheet B. This was due to the delays in pager notification (CI 7) and accounting for all personnel (CI 8).	☐

Figure 2.1 Example Partial Index of Subevents



Code	Description
CI1	Safety Relief Valves (SRVs) rebuilt at Wyle (vendor) test facility incorrectly. Plunger jam nuts were not torqued adequately to the valve stem, and Loctite threadlock compound was not used as required by vendor assembly instructions.
XHE1	New fittings installed on the SRV pilot solenoid valve connections and tubing replaced on F, H, J, K, and L pilot solenoid valves, which involved cutting of 300 series stainless steel with either a hacksaw or an aluminum oxide grinding wheel directly at or upstream of the affected locations. A flush was not performed following this maintenance.
XEQ1	Nitrogen leak discovered and foreign material found in pilot solenod valve of G SRV.
XEQ2	Additional solenoid valve failures found (SRVs H, E, and L).
XHE3	Licensee began efforts to clear the lines: disconnect, blowdown, reconnect, recycle. Blowdown efforts and/or test acceptance criteria inadequate, as flush was stopped before all SRVs were clear of foreign material.
CI2	Licensee determined they had a condition with five of the main SRVs that could prevent ADS safety function. 4-hour notification issued to NRC at 1130
XEQ3	J SRV valve failed to reseat.
HS1	7 SRV pilot solenoid valves replaced (A, B, F, H, J, K , and L) and 4 SRV pilot solenoid valves rebuilt (C, D, E, and G).
XHE4	Excessive Loctite used when rebuilding G SRV.
PS1	Plant begins power ascension.
XEQ4	G SRV fails to open.
PS2	Remaining SRVs cycle satisfactorily.
HS2	G SRV replaced.
PS3	G SRV tested satisfactorily.

Figure 2.2 Example Graphical Timeline

2. *Lessons Learned*: This section is used to explain any key lessons learned from this event, or any key corrective actions taken as a result of this event, if that information is available. This section may be used to describe consequences of the event beyond the involved plant. This could include company- or industry-wide notices of lessons learned, regulatory notices or changes, procedural changes, etc.

2.3.4.7 Section 5: Human Subevent Dependency Table

To complete the timeline information, the HERA analysts should also complete the dependency matrix, in which the relationship among XHEs is identified. Because HRA methods do not typically model the relationship between human errors and successful human actions, dependency is only completed for XHEs and XHE clusters. The approach to dependency in HERA offers analysts the opportunity to document dependency.

The goal of HERA is to document the facts of human performance from occurred events or simulation scenarios. Thus, event coding is a deterministic and retrospective process. As a result, dependency is defined differently in HERA from HRA methods, which model dependency from a probabilistic and predictive perspective. In HERA, dependency is identified only when there is clear evidence that a common condition or common mechanism caused two or more human failures within the same event. Thus, subevents triggered by a common cause are generally considered as dependent.

When determining dependency, analysts should first consider whether common conditions exist between two XHEs and then whether and how the two subevents may be related. HERA provides comment fields for the analyst(s) to justify the dependency. A list of possible dependency mechanisms is embedded in the dependency matrix of HERA Worksheet A and is provided in the dependency section of the HERA software. For example, in a situation in which instrumentation failure causes misleading indicators that in turn results in a series of human failures, these error subevents are dependent. In this case, the initiator of the dependency is not a human failure but a hardware failure. Because such a hardware failure is not captured in the dependency matrix of human subevents (XEQs are not considered for dependency), a special note should be made in the comments section to denote a CCF condition and its shared effect on subsequent human performance.

Primarily, dependency accounts for common failure conditions in a chronological chain of subevents. However, subevents do not need to be contiguous to be dependent. It is possible for series of unrelated activities to occur in parallel during an overall event. For example, one series of actions (e.g., HFE1 and HFE3) may intermix chronologically with another, unrelated sequence of actions (e.g., HFE2 and HFE4). These subevent sequences do not occur in uninterrupted chronological order. The overall event sequence—HFE1, HFE2, HFE3, HFE4—may chronologically mask the two distinct and related subevent series. For this reason, it is possible within HERA to specify dependency for related activities that occur distributed over time. Thus, dependency serves as a way to link related activities or subevents, and even to bridge these activities when they are interspersed by unrelated activities.

It is important to distinguish between dependent subevents and subevent clusters, since both involve establishing a relationship between subevents. Recall from Section 2.3.4.4 that subevents may be clustered when they have the same goal, strategy, and context. Both positive and negative human subevents (HSs and XHEs, respectively) of the same type may be clustered. In contrast, dependency applies solely to negative human subevents and provides evidence of an increased likelihood of occurrence of one subevent to the next due to common conditions. It is possible for dependency to exist between subevents in an XHE cluster. To accurately identify dependencies, XHEs that are clustered for the purposes of Worksheet B analysis should be considered separately when assessing dependency.

A list of possible dependency mechanisms that are included in HERA is presented in Table 2.7 below. Note that these mechanisms overlap one another and should not be considered orthogonal. Also note that this list is not exhaustive. Analysts should freely record additional dependency mechanisms appropriate to the unique circumstances of the event. Any factor that reasonably triggers an increased likelihood of a negative outcome across subevents should be carefully considered as a candidate of dependency mechanism.

Once Worksheet A is complete, the analysts move on to the subevents and subevent clusters identified for Worksheet B coding.

Table 2.7 HERA Dependency Mechanisms

Dependency Mechanism	Discussion
Task	Task refers to the goal-driven activity performed by the crew. Each task represents different activities and corresponding different goals necessary to complete an action. A task may roughly correspond to a step of a procedure or may be defined at a finer grain corresponding to a series of actions required by each procedural step. If the second subevent involves a different task than the first, then dependency is very unlikely. If the two subevents involve the same or closely related tasks, however, dependency is possible. If, for example, an operator misreads a procedure step that causes him or her to go to the wrong subsequent procedure step, both actions share a common task of following procedures and could be considered dependent.
Crew / Person	Crew is broadly defined as those personnel who individually or as a team carry out plant activities. If the crew (or operator) involved in the first subevent is the same as is involved in the second subevent, there is a greater chance that dependency can exist between the subevents. This dependency may be related to the sub-optimal performance by a particular crew carrying forward to subsequent tasks. However, even if there is a different person or crew, if the culture or mindset is the same at the second subevent as the first, dependency is possible. Such would be the case for management sanctioned workarounds, in which two different crews have an established pattern of activity that does not differ between them and results in an undetected unsafe plant state. See also “Organizational/Team Culture” and “Mindset” below.
Time	Generally speaking, if two subevents occur closely together in time, there is a greater possibility for dependency, as there is less opportunity for other factors (such as a different person or different cues) to intervene between the two subevents. When two subevents are close in time, there is less opportunity for recovery, since the ramifications of an error may not yet be apparent and there is inadequate time to diagnose the potential problem. However, it is possible for dependency to exist between subevents that are far apart in time, even years, if other dependency mechanisms are at play, such as culture or mindset. Maintenance issues are examples of subevents that may span a large time but still be dependent.
Location	The location of a series of crew activities is an important consideration for dependency. If the second subevent takes place in the same location as the first subevent, there is a greater possibility for dependency between the two subevents. Proximate activities do not afford additional context that may enable the crew to diagnose and recover from an error.
Cues	Additional cues such as instrument readings, feedback from other personnel, or system performance introduce new information that thwarts the escalation of an error between two subevents. If additional cues are present during the second subevent in the sequence, dependency between subevents is less likely. If, however, no additional cues are available, then there is a greater possibility for dependency to exist between the subevents. The crew lacks additional information that may enable it to diagnose and recover from an error.

Table 2.7, Continued

Dependency Mechanism	Discussion
Equipment / System	Equipment or system refers to those devices used by the crew to detect and control plant operations. It is important to recognize that the equipment or system is not synonymous with Location. Systems can be large and spread out over large areas, and equipment can, in some cases, be moved. If the equipment or system has an underlying characteristic (e.g., a stuck control valve) that causes the operators to perform a series of tasks incorrectly, then there is dependency between those tasks.
Unreliable system feedback	Unreliable system feedback (e.g., a misleading indicator or failed instrumentation) can contribute to dependency between actions in a task sequence by not allowing personnel to detect important underlying plant states or by leading personnel to a particular mindset (e.g., “do not trust the indicators”). Those faulty actions in response to the unreliable system feedback are dependent.
Action prompts next incorrect action	It is often the case that one error (often in judgment or diagnosis) leads the involved personnel down an incorrect path of action. In this case, dependency between actions in that path is very likely, as one error leads to subsequent errors. Additional cues or new personnel or mindset can break the path in such a situation.
*Work Control (see NRC Inspection Manual Chapter 0305 for update)	The licensee plans and coordinates work activities, consistent with nuclear safety. Specifically (as applicable): A. The licensee appropriately plans work activities by incorporating: • risk insights; • job site conditions, including environmental conditions which may impact human performance; plant structures, systems, and components; human-system interface; or radiological safety; and • the need for planned contingencies, compensatory actions, and abort criteria. B. The licensee appropriately coordinates work activities by incorporating actions to address: • the impact of changes to the work scope or activity on the plant and human performance. • the impact of the work on different job activities, and the need for work groups to maintain interfaces with offsite organizations, and communicate, coordinate, and cooperate with each other during activities in which interdepartmental coordination is necessary to assure plant and human performance. • the need to keep personnel apprised of work status, the operational impact of work activities, and plant conditions that may affect work activities. • the licensee plans work activities to support long-term equipment reliability by limiting temporary modifications, operator work-arounds, safety systems unavailability, and reliance on manual actions. Maintenance scheduling is more preventive than reactive.

Table 2.7, Continued

Dependency Mechanism	Discussion
*Work Practices (see NRC Inspection Manual Chapter 0305 for update)	Personnel work practices support human performance. Specifically (as applicable): A. The licensee communicates human error prevention techniques, such as holding pre-job briefings, self and peer checking, and proper documentation of activities. These techniques are used commensurate with the risk of the assigned task, such that work activities are performed safely. Personnel are fit for duty. In addition, personnel do not proceed in the face of uncertainty or unexpected circumstances. B. The licensee defines and effectively communicates expectations regarding procedural compliance and personnel follow procedures. C. The licensee ensures supervisory and management oversight of work activities, including contractors, such that nuclear safety is supported.
*Decision-Making (see NRC Inspection Manual Chapter 0305 for update)	Licensee decisions demonstrate that nuclear safety is an overriding priority. Specifically (as applicable): A. The licensee makes safety-significant or risk-significant decisions using a systematic process, especially when faced with uncertain or unexpected plant conditions, to ensure safety is maintained. This includes formally defining the authority and roles for decisions affecting nuclear safety, communicating these roles to applicable personnel, and implementing these roles and authorities as designed and obtaining interdisciplinary input and reviews on safety-significant or risk-significant decisions. B. The licensee uses conservative assumptions in decision making and adopts a requirement to demonstrate that the proposed action is safe in order to proceed rather than a requirement to demonstrate that it is unsafe in order to disapprove the action. The licensee conducts effectiveness reviews of safety-significant decisions to verify the validity of the underlying assumptions, identify possible unintended consequences, and determine how to improve future decisions. C. The licensee communicates decisions and the basis for decisions to personnel who have a need to know the information in order to perform work safely, in a timely manner.
*Resources (see NRC Inspection Manual Chapter 0305 for update)	The licensee ensures that personnel, equipment, procedures, and other resources are available and adequate to assure nuclear safety. Specifically, those necessary for: A. Maintaining long term plant safety by maintenance of design margins, minimization of long-standing equipment issues, minimizing preventative maintenance deferrals, and ensuring maintenance and engineering backlogs which are low enough to support safety. B. Training of personnel and sufficient qualified personnel to maintain work hours within working hours guidelines. C. Complete, accurate and up-to-date design documentation, procedures, and work packages, and correct labeling of components. D. Adequate and available facilities and equipment, including physical improvements, simulator fidelity and emergency facilities and equipment.

Table 2.7, Continued

Dependency Mechanism	Discussion
*Preventing, Detecting, and Mitigating Perceptions of Retaliation (see NRC Inspection Manual Chapter 0305 for update)	A policy for prohibiting harassment and retaliation for raising nuclear safety concerns exists and is consistently enforced in that: A. All personnel are effectively trained that harassment and retaliation for raising safety concerns is a violation of law and policy and will not be tolerated. B. Claims of discrimination are investigated consistent with the content of the regulations regarding employee protection and any necessary corrective actions are taken in a timely manner, including actions to mitigate any potential chilling effect on others due to the personnel action under investigation. C. The potential chilling effects of disciplinary actions and other potentially adverse personnel actions (e.g., reductions, outsourcing, and reorganizations) are considered and compensatory actions are taken when appropriate.
*Environment for Raising Concerns (see NRC Inspection Manual Chapter 0305 for update)	An environment exists in which employees feel free to raise concerns both to their management and/or the NRC without fear of retaliation and employees are encouraged to raise such concerns. Specifically (as applicable): A. Behaviors and interactions encourage free flow of information related to raising nuclear safety issues, differing professional opinions, and identifying issues in the CAP and through self assessments. Such behaviors include supervisors responding to employee safety concerns in an open, honest, and non-defensive manner and providing complete, accurate, and forthright information to oversight, audit, and regulatory organizations. Past behaviors, actions, or interactions that may reasonably discourage the raising of such issues are actively mitigated. As a result, personnel freely and openly communicate in a clear manner conditions or behaviors, such as fitness for duty issues, that may impact safety, and personnel raise nuclear safety issues without fear of retaliation. B. If alternative processes (i.e., a process for raising concerns or resolving differing professional opinions that are alternates to the licensee's corrective action program or line management) for raising safety concerns or resolving differing professional opinions exists, then they are communicated, accessible, have an option to raise issues in confidence, and are independent, in the sense that the program does not report to line management (i.e., those who would in the normal course of activities be responsible for addressing the issue raised).

*These dependency mechanisms are quoted directly from the cross-cutting components in the NRC inspection manual chapter (IMC) 0305. The discussions of these components are written in a positive tone. As dependency is typically considered between human failure events, readers should view the specifics discussed as mechanisms for reducing or increasing the incidence of dependency between subevents depending upon the extent to which the work processes promote safety. Safe work processes, as depicted above, tend to decrease the incidence of dependency between subevents. Conversely, poor work processes can increase the occurrence of human failures across time, in which case dependency between subevents is likely.

It is advised that the analysts finalize the Index of Subevents before moving on to coding the subevents into Worksheet B, because making changes to the timeline after Worksheet B coding has begun often results in revisions to the Worksheet B coding and additional processing time. Other sections of Worksheet A, such as Affected System(s), Affected Component(s), and the Dependency tables, may be easier to complete following Worksheet B analysis. Once the Index of Subevents is finalized, one analyst, typically the analyst with human factors and HRA experience, then codes each human subevent and subevent cluster using Worksheet B. It may be helpful for the analyst to print a paper copy of Worksheet A for reference while working on Worksheet B coding. The second analyst, typically the analyst with operations experience, reviews the completed set of worksheets prior to the event's entry into the HERA database.

2.3.5 Instructions for HERA Worksheet B

Because HERA serves as a repository for human performance information stemming from work in nuclear power plants (NPPs), HERA analysts only perform detailed analysis on subevents containing XHEs and HSs. Such information is captured in the Part B Worksheets or the equivalent in the software database. The HERA analyst completes a separate analysis for each XHE or HS subevent or cluster assigned for Worksheet B analysis.

Worksheet B serves to identify the details surrounding each subevent, including the personnel involved, contributory plant factors, specific systems, functions, and components affected by the subevent, contributing factors and PSFs, types or modes of human activity, and error type.

2.3.5.1 General Guidance

Before discussing instructions specific to the sections of Worksheet B, some general guidance is appropriate.

Acceptable Level of Inference

When coding subevents and identifying contributing factors (i.e., causes), the analysts should infer as little as possible, striving not to make assumptions beyond the information provided in the source document(s). However, reasonable, justifiable inferences may be made based on the information available and the analysts' professional knowledge and prior experience. When inferences are made, they should be clearly indicated as such and delineated from information explicitly provided in the source materials.

Comments and Explanations

The analysts shall provide an explanation, with reference to the source document, of all assignment of contributing factors, PSFs, error types, etc. This provides a justification for all assignments. The general rule in HERA is that every coding assignment made should be justified by evidence in the source documents or supported by documented analyst inference.

2.3.5.2 Subevent Information

1. *Source Document*: This is the same information as entered on Worksheet A, and serves to identify the event the subevent is associated with.
2. *Subevent Code*: Enter the unique subevent code associated with the subevent, as indicated on the Index of Subevents in Section 3 of Worksheet A.
3. *Description*: Enter the subevent description, as indicated on the Index of Subevents. If the Worksheet represents a cluster, indicate which subevents are clustered here and provide descriptions of all subevents.

These three items should automatically be populated from Worksheet A, if the analyst is working within the HERA software. If the analyst is using the Worksheets but not the HERA software, this information will need to be entered manually.

2.3.5.3 Section 1: Personnel Involved in Subevent

This section contains the same information as the Personnel field in Worksheet A. For users of the HERA database, changes made here will be reflected in Worksheet A, and vice-versa. Users of the worksheets will have to manually select the fields. The selections made here should be the same as the Personnel field in Worksheet A.

Personnel are grouped into categories, with a category-level heading (e.g., “Plant Support Personnel”) and a more detailed description (e.g., “Security”). This allows the analyst to select at the level of detail provided in the information source. As applicable, multiple personnel may be selected for any given subevent.

2.3.5.4 Section 2: Plant Conditions

1. *Contributing Plant Conditions*: Identify any actual plant and equipment conditions that contributed to the subevent. This list, based partially on Halden Reactor Project Report HWR-521 (Braarud, 1998), summarizes plant conditions that contributed to the subevent or influenced the decisions and actions of the personnel. If significant plant factors were at play in the subevent but are not listed, the analyst may specify “Other” and provide details in the corresponding text entry field. Temporally, this section identifies *prior* plant conditions that affected the subevent in question.
2. *Effects on Plant*: These fields are automatically populated with the affected function(s), system(s), and component(s) selected in Worksheet A. Select which, if any, function(s), system(s), and component(s) that this subevent affected. Users of the worksheets will have to enter this information manually. Use Appendix C as a guide.
   a. Affected Function(s)
   b. Affected System(s)
   c. Affected Component(s)

   Temporally, this section identifies plant function(s), system(s), and/or component(s) that are *subsequently affected by* the subevent under analysis.

2.3.5.5 Sections 3, 4, and 5: Performance Shaping Factors

Sections 3, 4, and 5 collect information about PSFs that influenced the subevent. Before instructions specific to each section are given, it is necessary to discuss PSFs in general and explain the relationship between the sections in the worksheet.

Performance shaping factors (PSFs) provide a means of tracing either the detrimental or positive effect on human performance. HERA’s PSFs were developed by merging the SPAR-H PSFs (Gertman et al., 2005) and performance factors covered in *Good Practices for Implementing HRA* (Kolaczkowski et al., 2005):

- *Available Time*: refers to the time available to complete a task. In HERA, available time considers the time available versus the time required to complete an action, including the impact of concurrent and competing activities.
- *Stress and Stressors*: are broadly defined to describe the mainly negative, though occasionally positive arousal that impacts human performance. A small amount of stress can be beneficial and enhance performance. More often, stress contributes to performance detriments. When evaluating the impact of stress as a PSF, analysts should consider workload, task complexity, time pressure, perceptions of pressure or threat, familiarity with

the situation at hand, physical stressors such as those imposed by environmental conditions (e.g., high heat, noise, poor ventilation, poor visibility, or radiation). Clearly, stress is context-dependent; it is not independent of other PSFs. If other PSFs such as available time, complexity, training, or fitness for duty are poor, it is probable that stress is elevated. Analysts should consider the situation as a whole, including the other relevant PSFs, when assessing stress as a PSF.

- *Complexity*: Refers to how difficult the task is to perform in the given context. Complexity considers how ambiguous or familiar the situation or task is, the number of separate inputs that are in mind simultaneously and possible causes, the mental effort and knowledge required of a task, the clarity of cause-and-effect relationships in task performance and system response, the number of actions required in a certain amount of time, and the physical effort or precision required. It also considers the environment in which the task is to be performed, any special sequencing or coordination that is required (e.g., if it involves multiple persons in different locations), the presence and number of parallel tasks or other distractions, and the presence and quality of indications. The more complex a task is, the greater the chance for error.
- *Experience and Training*: Included in this consideration are years of experience of the individual or crew, specificity of training to the work being performed, quality of training, and amount of time since training. This also includes how frequently an activity is performed (e.g., routinely vs. rarely) and an operator's familiarity or experience with a task or situation.
- *Procedures and Reference Documents*: refers to the availability, applicability, and quality of operating procedures, guidance or reference documents, or best practices for controlling work quality for the tasks under consideration. It can also refer to policies and rules or regulations that govern work at a plant. When assessing the influence of procedures and reference documents on a subevent, analysts should consider the degree to which the available procedures clearly and unambiguously address the situation at hand, completeness, accuracy, the degree to which procedures assist the crew in making correct diagnoses, the extent to which persons have to rely on memory, and how easy or difficult the procedure is to read, follow, or implement.
- *Ergonomics and Human-Machine Interface*: This is a broad category that encompasses all aspects of how persons interact with the plant systems, equipment, data or information interfaces, instrumentation, and other aspects of their environment. Included in this PSF are the availability and clarity of instrumentation, the quality and quantity of information available from instrumentation, the layout of displays and controls, the ergonomics of the control room or work location, the accessability and operability of the equipment to be manipulated (e.g., to manually open a valve requires an operator to climb over pipes and use a tool from an awkward position), the extent to which special physical fitness requirements, tools or equipment are needed to perform a task. The adequacy or inadequacy of computer software is also included in this PSF.
- *Fitness for Duty/Fatigue*: refers to whether or not the individual performing the task is physically and mentally fit to perform the task at that time. This includes such considerations as fatigue, illness, drug use (legal or illegal), physical and mental health, overconfidence, personal problems, time of day, and work schedule.
- *Work Processes*: refer to aspects of doing work, including intra-organizational collaboration, work planning, communication, and management support and policies. Work Processes is divided into four sub-categories:
  - *Planning and Scheduling*: Those contributing factors to a subevent that involve planning work activities and scheduling. Work planning includes work package development and ensuring that personnel have enough resources (e.g., tools, materials, or funding) to perform work. Scheduling includes ensuring sufficient and appropriate personnel are

    available to perform work. It also includes ensuring that personnel do not work too much overtime.
  - *Supervision and Management*: Contributing factors to a subevent that involve supervision of work and organizational or management issues. This includes such factors as command and control, quantity, quality, and appropriateness of supervision, whether work orders or instructions are given clearly, management emphasis on safety, weaknesses and strengths in organizational attitudes and administrative guidance, and organizational acceptance of workarounds.
  - *Conduct of Work*: Contributing factors to a subevent that involve performance of work activities, at both the individual and group level. This includes such factors as procedural adherence, whether work is done in a timely manner, appropriate or inappropriate use of knowledge and available information, recognition of adverse conditions, ability to coordinate multiple tasks, and proper use of tools and materials.
  - *Problem Identification and Resolution (PIR)/Corrective Action Program (CAP)*: All contributing factors to a subevent that involve identifying and resolving problems at a plant. This includes factors such as classification of issues, root cause development, planning and implementation of corrective actions, review of operating experience, trending of problems, individuals' questioning attitudes and willingness to raise concerns, and preventing and detecting retaliation.
- *Communication*: refers to the quality of verbal and written interaction between personnel working together at the NPP. This includes whether the content of communications are clear, complete, are verified and managed in such a way to ensure their receipt and comprehension, as well as whether one can be easily heard.
- *Environment*: refers to external factors such as ambient noise, temperature, lighting, weather, etc., which can greatly influence the ability of personnel to carry out their prescribed tasks.
- *Team Dynamics and Characteristics*: refers to the crew interaction style and whether it is appropriate to the situation at hand. At first glance, some aspects of this factor are related to the Communication PSF, such as quality of communication strategies used by the crew, and the supervision and conduct of work subcategories of the Work Processes PSF, such as style of supervision and procedural adherence. However, this PSF is specific to characterizing the crew as a whole and how the dynamics within or between teams influence performance and event response. Specifically, team dynamics and characteristics include such aspects as the degree to which independent actions are encouraged or discouraged, supervision style (e.g., democratic or authoritarian), presence of common biases or informal rules, such as how procedural steps are to be interpreted or which steps can be skipped, how well the crew ensures that everyone stays informed of activities or plant status, and the overall approach of the crew in responding to an event, such as aggressive or slow and methodical (Kolaczkowski, et al, 2005). It is important to note that HERA does not identify any one type of crew interaction style as "better" than others; the effect of crew characteristics is largely dependent on the situation under analysis and whether the crew dynamics were appropriate to that situation.

Sections 3 and 4 of HERA Worksheet B list many possible details about contributing factors to human performance: Section 3 lists positive contributing factors, and Section 4 lists negative contributing factors. The analysts use these sections to indicate the specific factors that influenced the subevent in question. Sections 3 and 4 can be seen as the objective evidence of PSF influence on the subevent in question.

Details in both Section 3 and Section 4 are categorized by performance shaping factor. The details vary in level of specificity to accommodate varying levels of detail in the source documents: some details are highly specific, while others are more general. In cases where two or more details in a PSF category seem similar, the difference between them is usually level of specificity. For example, in Fitness for Duty, “Unfamiliar work cycle” is specific, allowing for instances where such an issue is explicitly discussed in the source, whereas “Circadian factors” encompass all instances where time of day or bodily rhythm was an issue but further details are not specified. As another example, in the PSF of Procedures and Reference Documents, the detail of “Procedure/reference document technical content less than adequate (LTA)” is general enough to apply to all instances of the procedure content being inadequate, whereas “Procedures do not cover situation” is specific to instances of not having a procedure for the situation at hand.

It is important for the analysts to keep temporal issues in mind when considering the influence of each PSF. During previous coding efforts while the HERA database and method were being developed, a common mistake in PSF detail assignment came to light: analysts were assigning PSF details that were a part of the subevent being coded, rather than identifying details that *contributed to* the subevent. For example, presume that the subevent under analysis is an XHE where the corrective action taken to fix a degraded valve did not correct the problem. It would be incorrect to assign the negative PSF detail of “Corrective action less than adequate (LTA)” because the poor corrective action is the subevent under analysis. It would only be appropriate to make such an assignment if some *other* poor corrective action contributed to the XHE in question.

The analyst(s) should only check *separate, prior* or *already existing* factors that *contributed to* the subevent in question. In other words, the PSF details selected for a subevent should not describe the subevent in question, but should identify factors that contributed to the subevent under analysis. To aid the analysts with this issue, it is recommended that the Contributory Factors listed in Sections 3 and 4 generally should be seen as “causes” and the subevent being coded can be seen as the “effect”. To resolve questions about whether a specific PSF detail should be assigned, analysts may use the following statement as a guide:

> “[PSF detail under consideration] contributed to [summary statement of subevent being analyzed].”

Using this statement, the example discussed above would read:

> “[Less than adequate corrective action] contributed to [a less than adequate corrective action].”

If the resulting sentence does not make sense based on the available information, as would be the case in this example if some other poor corrective action did not contribute to the inadequate corrective action taken on the degraded valve, the PSF detail should not be assigned.

It is also important for the analyst(s) to assess the influence of PSFs for each subevent or subevent cluster independently. Even if a particular PSF had an impact on other subevents, its influence on the subevent under analysis should not be assumed. Analyst(s) should always review source documents for each subevent and code only those factors that affected each individual subevent being coded.

Sections 3 and 4 of HERA are to be coded for both XHEs and HSs. It is possible for people to make mistakes despite good PSFs, just as it is possible for people to succeed despite strong negative PSFs. In practice, it will more often be the case that XHEs have mostly negative PSF details and HSs have mostly positive PSF details, but HERA allows for all possibilities.

Section 5 serves as a summary and ranking of the information collected in Sections 3 and 4. This section can be seen as a subjective evaluation of the evidence provided in Sections 3 and 4. Based on the details selected in those sections, the analyst(s) make a judgment of the level of influence of each PSF. Descriptions of each level are:

- *Insufficient Information*: There is no information available in the source documents to support assigning a PSF level.
- *Good*: Human performance is enhanced by the PSF in question.
- *Nominal*: Human performance is not affected by the PSF in question, or the PSF does not appear to play a role.
- *Poor*: Human performance is negatively affected (degraded) by the PSF in question.

Do not "default" to nominal. When ranking the PSF influence, it is recommended that the analyst(s) *start* at Insufficient Info and move to Good, Nominal, or Poor based upon the available information. The general rule in HERA is that every coding assignment made should be justified by evidence in the source documents or supported by documented inference; therefore a PSF should not be ranked as "Nominal" unless that level is supported by the data in the event source.

Some general guidance for Section 5:

What happens to the PSF level assignment if both positive and negative details are selected in a single PSF for a single subevent? Judgment on the part of the analysts is required. Generally, the contributing factor that has the greatest impact on the subevent should be weighted more heavily. In a case where both the positive and negative factors of the PSF are equally influential, the analysts may "average" them to obtain a nominal weight if, in their judgment, they cancelled one another. Judgment is required, and it is advised that such cases be discussed within the coding team.

For example, in one event at a pressurized water reactor (PWR), an automatic reactor trip occurred because a steam generator feed pump unexpectedly tripped and operators were unable to reset the pump trip. This caused the water level in the steam generators to drop until the reactor tripped. When this occurred, the reactor regulating system (RRS) automatically opened the turbine bypass valves (TBVs) and atmospheric dump valves (ADVs) with a "quick open" signal to control RCS temperature. The quick open signal was designed to fully open the TBVs and ADVs initially, then modulate, to automatically control RCS temperature at 532°F. However, due to inadequate design in relay contacts, the ADVs remained fully open, causing a rapid overcooling and depressurization of the RCS. Ten minutes following the trip, operators transferred control of the ADVs to the auxiliary shutdown panel to remove the "quick open" signal, and the ADVs closed and the cause of the overcooling and depressurization was terminated. This successful operator action was represented by a HS subevent.

For this subevent, there were both positive and negative PSF details for "Experience and Training". The simulator training for this event was regarded as poor, due to substantial differences between the simulator training and the behavior of the physical plant under transient conditions. However, the operator's good knowledge of the plant and the valve control logic allowed them to isolate the faulted circuit and terminate the cause of the overcooling. In this case, the good general training had a stronger influence on this subevent than the less effective simulator training, and the PSF would be ranked as “Good”.

Section 3: Positive Contributory Factors / PSF Details

As stated above, Section 3 is to be coded for both HSs and XHEs. This table lists positive contributors beyond the nominal state. The positive contributory factors are grouped according to the PSFs used in HERA. For each assigned contributory factor, the analyst(s) should indicate if the selection was made based on evidence directly from the source or based on inference. All assignments should also be explained using the comment fields.

Section 4: Negative Contributory Factors / PSF Details

As stated above, Section 4 is to be coded for both HSs and XHEs. The analyst uses this field to indicate any negative factors that contributed to the subevent. This section is the counterpart to the positive contributory factors and applies only for PSF contributors that fall below the nominal state. Items in parentheses cross-reference sections where HERA structural elements have utilized existing HFIS (US NRC, 2006) structures. The parentheses identify the item in HFIS from which the HERA structure is copied (e.g., W2 185).

Section 5: Performance Shaping Factors

Based on selections made in Sections 3 and 4, decide if each PSF was good, nominal, poor, or if there was insufficient information to make a determination. For the Work Processes PSF, rank each sub-category as well.

2.3.5.6 Section 6: Human Cognition

This section assesses two distinct perspectives of the human mental activity associated with the subevent being coded. The first considers the steps in human information-processing or decision-making, while the second considers the level of conscious engagement in the activity at hand. This section allows the analyst(s) to indicate the type of activity the person is engaged in, and where the error(s) or success(es) took place. The analyst(s) should complete this section for both XHEs and HSs.

Human Information Processing:

When considering how to assign human subevent codes, it is useful to consider the cognitive activities that are involved in decision making or problem solving, including:

- Detection or recognition of a condition or change in situation (e.g., a problem or alarm)
- Interpretation of the condition or change in situation
- Planning a response to the situation
- Executing the response (action)
- Monitoring and process control, prior to, during, and following a set of actions

This information is useful for a variety of HRA methods, which often weight PSFs differently depending on whether the HFE under analysis involves diagnosis (detection, interpretation, and planning) or action. Humans can make mistakes at any of these steps. Consider the following:

- If a problem is not recognized as such, subsequent corrective actions may not be performed. Alternately, if a problem is observed but mis-classified (i.e., mis-diagnosed), then subsequent corrective actions may be ineffective or counter-productive.
- Even if recognition and interpretation of a problem are performed well, an effective corrective action is still needed. An incorrect plan can worsen the situation or render actions ineffective.
- If planning is inadequate, then the execution of the planned actions is more likely to not bring about the desired results.
- Errors can also be made in implementing the planned actions, even when the situation is understood, an effective plan is made, and an effective action plan is undertaken.

As discussed in Section 2.3.3.1, the HERA subevents XHE and HS are related to the effects of a human action on the plant or other personnel. XHE and HS are defined from a *plant-centered* perspective, not a *human-centered* perspective. This section on human cognition was added to HERA to evaluate error and success from a human-centered perspective. Human error occurs whenever a human action or sequence of actions fails to achieve its intended outcome, when the failure cannot be attributed to chance (Reason, 1990). Conversely, success occurs whenever a human action or sequence of actions achieves its intended outcome, when that success cannot be attributed to chance. This end result can be a result of failure or success during one or more of the above activities of human information processing.

Depending on how subevents are broken down, it is possible to see all of these steps within one XHE or HS, or for the steps to be split up into separate subevents, particularly if more than one error or success is made within the process. This section allows analyst(s) to indicate where in this process the error or success occurred, regardless of the subevent breakdown. Consideration of this process during timeline development can assist subsequent coding.

Using the second example in 2.3.4.4 13.b above, following an excessive cooldown after a reactor trip, operators erroneously decided to heat the RCS loop, which caused an increase in pressurizer level and pressure. As a result of this decision, operators had to take several steps, including manually increasing main spray to control the pressure increase and removing charging pumps from service to control the pressurizer level increase. There were several errors in this action sequence. The incorrect decision to heat the RCS was based on an inadequate understanding of the event in progress, or an incorrect interpretation. The plan to heat the RCS did not represent a planning error, as it was based on the earlier interpretation error, but because it was unsafe for the plant, it was coded as an XHE. The subsequent step of manually increasing spray was also an XHE, because it was unsafe for the plant, but it did not represent an action error. It was a correct action based on the prior error in interpretation. However, when operators removed charging pumps from service, also an XHE as it was unsafe for the plant, they performed this step late. This represented an action error after an interpretation error. See Table 2.8 for an illustration of how the above example would look if the second XHE was coded in HERA Worksheet B.

For each step in the process, the analyst(s) should indicate whether the step was correct, correct based on a prior error in the sequence, or incorrect, if enough information is available to make that determination. The analyst(s) should consider the whole sequence, up to the subevent under analysis, regardless of whether a prior step is in a separate subevent or not.

Cognitive Level

Rasmussen's skill-rule-knowledge framework of cognitive control mechanisms distinguishes between performance levels (Reason, 1990).

Table 2.8 Example of Errors in the Human Information Processing Steps

Step		Comment
Detection: Detection or recognition of a stimulus (e.g., a problem, alarm, etc.)	⊠ Correct detection ☐ Correct detection based on incorrect information ☐ Incorrect detection ☐ Not Applicable / Insufficient Information	Operators were aware of the RCS cooldown.
Interpretation: Interpretation of the stimulus (e.g., understanding the meaning of the stimulus)	☐ Correct interpretation ☐ Correct interpretation based on incorrect detection ⊠ Incorrect interpretation ☐ Not Applicable / Insufficient Information	Operators had a poor understanding of RCS temperature/pressure/ pressurizer level dynamics and incorrectly interpreted plant parameters to indicate that a RCS heat up was the appropriate action to take.
Planning: Planning a response to the stimulus	☐ Correct planning ⊠ Correct plan based on incorrect interpretation / detection ☐ Incorrect plan ☐ Not Applicable / Insufficient Information	Decision to heat the RCS (XHE a) was correct given their understanding of the event, but it was not the appropriate action to take and complicated recovery from the transient.
Action: Executing the planned response	☐ Correct action ☐ Correct action based on incorrect plan / interpretation / detection ⊠ Incorrect action ☐ Not Applicable / Insufficient Information	Other actions that were a part of the plan to heat the RCS were correct given their incorrect understanding of the event, but operators did not remove the charging pumps (XHE b) in a timely manner.
Indeterminate	☐ Indeterminate	

Skill-based level: This level describes human performance that is routine, highly-practiced, and carried out in a largely automatic fashion, with occasional conscious checks on progress. When working at this level, the operator is highly familiar with the environment or task. Errors made when in this mode tend to be slips or lapses (see 2.3.5.7 Section 7).

Rule-based level: At this level, operators tackle familiar problems via application of memorized or written rules (e.g., if *x* then *y*, etc.), with conscious thinking to verify the correct rule to use and to verify if the resulting solution is appropriate. Errors made when in this mode tend to be mistakes due to application of the wrong rule or incorrect recall of procedures.

Knowledge-based level: This mode describes human performance in novel situations for which rules are not available or when the available rules do not directly apply. Operators are required to use conscious analytical processing and stored knowledge to develop a solution to the problem at hand. Knowledge-based tasks require conscious, effortful thought or problem solving, and as such, processing when in this mode tends to be slow, sequential, laborious, and resource-limited. Errors at this level tend to be mistakes that arise from resource limitations, inadequate understanding of the problem, overconfidence, or incomplete or incorrect knowledge.

It is important to note that these three levels are not mutually exclusive—a person can work at all three levels at the same time. For example, take the process of driving a car (Reason, 1997). Controlling speed and steering the car is largely automatic, performed at the skill-based level. Dealing with other drivers, pedestrians, and following traffic signals is performed at the rule-based level. This can also be largely automatic, particularly when nothing happens to require the driver to consciously assess the situation or determine when other rules apply (e.g., avoiding a collision). At the same time, the driver can also be working at the knowledge-based level, for example, thinking about ways to solve a problem at work. The driver would be consciously aware of his or her thoughts at the knowledge-based level and any instances where attention was required at the rule-based level, but the driver may not consciously recall routine rule-based actions and activity at the skill-based level.

HERA analysts should indicate the appropriate cognitive level(s) involved in the subevent, if there is sufficient information available to make that determination, and then indicate whether performance at that level was correct or not.

2.3.5.7 Section 7: Error Type

This section utilizes two separate error taxonomies for classifying the XHE, and as such, it only applies to XHEs. Code for XHEs only.

Error of Omission/Error of Commission

An *Error of Commission* (EOC) is an incorrect, unintentional, or unplanned action. This occurs when a person makes an overt action, or *commits* an action that is incorrect. An error of commission typically leads to a change in plant or system configuration with the consequence of a degraded plant or system state. Examples include inappropriately terminating running safety-injection pumps, closing valves, and blocking automatic initiation signals.

An *Error of Omission* (EOO), on the other hand, is a failure to take a required action, which typically leads to an unchanged or inappropriately changed plant or system configuration with the consequence of a degraded plant or system state. Examples include failures to initiate standby liquid control system, start auxiliary feedwater equipment, and failure to isolate a faulted steam generator.

The classification of errors as omissions or commissions originated in PRA; the dichotomy of omission-commission is well-suited to the binary event trees used in PRA modeling. From a PRA perspective, errors of omission and commission are seen as opposites, literally meaning not doing something and doing something, respectively (Hollnagel, 1998). From the perspective of HERA analysts, however, this classification may prove to be problematic, as the categories are not mutually exclusive. For example, if an operator opens the wrong valve, she or he has failed to open the correct valve (an omission) and opened the incorrect valve (a commission). Many such errors of commission have underlying errors of omission. Because of this, it is necessary to provide additional guidance in order to assist analysts in making this determination.

The dichotomy of omission-commission serves to categorize the result or manifestation of human error (Hollnagel, 1998): a required action was not performed (omission), was performed incorrectly (commission), or an incorrect action was performed (commission). This classification system says nothing about the cause of the error, however, as an error in any step of the human information process (as discussed in Section 2.3.5.6 above) can result in an omission or a commission. For example, failure to correctly interpret a problem can result in operators taking no action (e.g., if they interpreted a situation as unimportant), or it could result in operators taking an incorrect action (e.g., if they misunderstood the situation to indicate a problem with the wrong system).

Probabilistic risk assessment historically has been interested primarily in omissions, which fit into a PRA event tree model. One of the purposes of HRA is to estimate the probability of failure of human action at key steps in the PRA model; as a result, HRA uses the omission-commission classification to provide information at the level of detail required by PRAs. In recent years, HRA practitioners have recognized the need to identify the causes of omissions and commissions. This has resulted in consideration of the steps in human information processing and development of models such as Rasmussen's cognitive levels and the slip/lapse/mistake error taxonomy, among others. The omission-commission dichotomy is still employed in a variety of HRA methods as a useful way to categorize the manifestations of human errors.

Information that indicates the cause of an omission or commission is collected elsewhere in HERA, in Section 6: Human Cognition (Human Information Processing and Cognitive Level; see Section 2.3.5.6 above), and Section 7: Error Type (see discussion of Slip/Lapse/Mistake/ Circumvention/Sabotage below).

For the purposes of HERA analysis, an XHE should be classified as an omission only if there is no associated commission. An error of commission with an underlying omission should be categorized as a commission. The analyst should indicate which of these two error types applies to the subevent under consideration and provide an appropriate explanatory comment.

Slip/Lapse/Mistake/Circumvention/Sabotage

This error taxonomy is related to Rasmussen's cognitive control framework, but has been expanded to include circumventions and sabotage. It is possible for an XHE to involve more than one category of error, so the Coder should select all options that apply. For example, it is common for a circumvention to be made based on an incorrect understanding of the situation (mistake). As discussed in the PSF section above, the difference between some of the details in each category is often one of generality versus specificity.

Slips or *Lapses* are the category of errors that occur when a person intends to take the correct action, but either takes a wrong action or fails to take the action they intended due to an attention failure (a slip) or a memory failure (a lapse) in a routine activity. In spite of a good understanding of the system (process, procedure, and specific context) and the intention to perform the task correctly, an unconscious unintended action or a failure to act occurs or a wrong reflex or inappropriate instinctive action takes place. Simple examples would include turning a wrong switch when the correct one is located next to it or inadvertently leaving out a step in a procedure when the intention was to complete the step.

Mistakes are the class of errors that occur when a person is following a plan diligently, but the plan is inadequate to achieve its goal. A mistake occurs when an intended action results in an undesired outcome. Mistakes can be rule-based, as when an inappropriate rule or procedure is selected for a situation or when a good rule is misapplied, or knowledge-based, as when the situation is not fully understood and no rules are available to aid operators in solving the problem.

Circumventions are the class of errors that occur when, in spite of a good understanding of the system (process, procedure, specific context), a person deliberately violates rules, prescriptions, good engineering practices, etc., without malevolent intention, usually with the intention of maintaining safe or efficient operations. It is possible for the outcome of such a circumvention to be successful, such as if the rules did not apply or did not work and creative problem-solving was required, in which case the subevent would likely be a HS. However, it is often the case that such a circumvention could result in a degraded plant condition.

Sabotage includes the class of errors that encompass an intentional breaking of known rules, prescriptions, etc., with malevolent intention.

2.3.5.8 Section 8: Subevent Comments

This section is to be used for any remaining comments, explanation, or information that is helpful in understanding the subevent being coded, as necessary.

2.3.6 External Review

Once Worksheet A and all the subevents assigned to Worksheet B coding have been completed, the event, including Worksheet A and all Worksheet Bs, should be sent to other analyst(s) for review. At this point, the primary analyst should indicate whether he or she had any questions or uncertainties about the coding for the second analyst to address. Typically, the second member of the coding team will review the analysis. This is accomplished within the HERA database by submitting the event through the database's review mechanism. Otherwise, it may be done through another review process of the analysts' choosing.

Chapter 4 discusses the final steps of the HERA coding process, including Clerical Check and External Review.

3 USE OF SIMULATOR DATA IN HERA

3.1 Introduction

As noted in the first volume of the HERA NUREG reports, some data sources such as LERs may not offer rich detail into human performance during an event. This lack of detail is largely due to the retrospective nature of event reporting. A careful and costly reconstruction of operating events by an Inspection Team is not always feasible, nor is it always necessary, especially when the risk significance of an event is negligible.

One data source that can consistently provide a complete snapshot of human performance is control room simulator studies. Simulator studies present opportunities to compare actual crew performance to procedural requirements and attempt to discern causes for any deviations. Studies such as those conducted at the HAlden huMan-Machine LABoratory (HAMMLAB; see Bye et al., 2006) provide insights into nuclear power plant control room crews when confronted with a variety of normal and off-normal scenarios. Unique to such studies is the ability not only to record all crew interactions and communications but also to:

- manipulate the scenario and corresponding external PSFs (e.g., environmental factors, quality of the interface, number of simultaneous tasks, etc.);
- precisely assess performance measures (such as time to complete tasks) that clearly map to the PSFs used in HERA; and
- utilize additional measures such as crew self-assessment of performance during the scenario.

HERA includes provision for the input of simulator studies. This chapter provides a brief overview of the differences between event and simulator study data. This chapter also provides suggestions for obtaining relevant human performance data for a HERA analysis from a simulator study and for organizing those data in a format suitable for input into HERA.

3.2 Differences Between Simulator Studies and Event Reports

3.2.1 Initiating Events

Simulator crews may successfully operate the simulated plant, despite negative influences that could lead to a hypothetical initiating event. Such situations occur every day at actual operating plants. But, because these operations never degrade below a minimum safety threshold, they are rarely reported. Consequently, there are few extensive records of the routine but safe human actions at plants. Thus, simulator studies represent the opportunity to record human performance during normal operations. Such activities may prove important baselines against which operator performance in off-normal circumstances can be compared.

For those simulator studies that feature negative plant states, it must be noted that these states are often triggered by the investigator. For example, a steam generator tube rupture (SGTR) may be artificially initiated by the investigator to gauge subsequent crew response. For artificially initiated events, the focus of the study is not on the root cause of the initiator but on the crew's post-initiator performance. Safe post-initiator crew performance is characterized by activities that address the unsafe initiator.

3.2.2 Simulator Data Types

Simulator studies pose unique data challenges in terms of the types of data that are gathered. Simulator studies are generally ideally suited to gather crew response time (e.g., Park & Jung, 2007; Roth, Mumaw, & Lewis, 1994). However, a simulator study must be carefully designed in order to record the data required for a comprehensive HERA analysis. PSF data are not readily extracted from simulator data simply by virtue of the data coming from a controlled study. Rather, the study needs to be designed to account for the data needed by HERA, and appropriate measures such as independent and dependent variables must be incorporated into the study.

Thus, while it would be desirable to use data derived from training simulator log files, such data do not automatically lend themselves to a full spectrum of HERA analysis. In order to complete a HERA analysis, it is crucial to understand what factors were manipulated, what crew-related PSFs came into play, as well as the scenario outcome in terms of success or failure. These factors are not guaranteed to be recorded in training simulator runs. Extraction of such factors can prove laborious and time-consuming when not incorporated into the original study design.

Braarud et al. (2007) note measures that are used in HAMMLAB control room simulator studies. These measures provide an example of how and what human performance information is collected at the Halden facility. Braarud et al.'s measures are listed below:

- Open-ended crew interview;
- Operators' PSF self-ratings and comments;
- Operator background questionnaire;
- Expert observer's PSF ratings, comments and crew performance rating;
- Itemized crew activity log for crew;
- Verbal protocol or commentary of crew activity by expert observer;
- Time-stamped simulator logs including all crew interactions with system;
- Audio and video of all crew members during the scenario.

3.2.3 Simulator Study Timeline

An event report, as illustrated earlier in this document, is deconstructed into an event timeline that chronicles positive and potentially negative human, plant, and contextual subevents at the plant. In contrast, a simulator study does not necessarily produce a single timeline, as a scenario is typically tested using multiple crews that may experience different outcomes. As such, it is important to construct an a priori timeline based on the different phases of a scenario. Consider, for example, a study to detect and control an SGTR at a pressurized water reactor. Appropriate high-level tasks of these activities might include:

- Detect and identify SGTR
- Isolate steam generator (SG)
- Cool down reactor cooling system (RCS)
- Depressurize RCS
- Terminate safety injection
- Achieve pressure balance

These phases could be further parsed into subtasks. For example, to isolate the SG, the operators would need to isolate the faulted SG according to emergency operating procedures, set the steam dump atmosphere valve set point to the appropriate pressure level, and alert personnel and emergency organizations.

Given the low human error probability for most control room tasks, each crew will ideally perform each of these tasks as prescribed by the operating procedures. Thus, the timeline for a simulator study may consist entirely of Successful Human Actions (HSs), something that is less common in analyses of reportable events. Naturally, there is also the possibility that certain simulator crews will fail to complete all required activities successfully based on the specified success criteria (e.g., time). Such actions may be recorded as XHEs.

Given the same scenario and phases across multiple crews, how should HERA analysts construct the scenario timeline? There are special considerations for simulator study data in terms of the level of task decomposition and the input of data from multiple crews.

3.2.3.1 Subevent Granularity

The granularity of the subevent decomposition is a reflection of the data collection goals. Using the above SGTR example, the analyst may be interested in the detailed steps each crew takes to complete each task. In such a case, the subevent timeline will feature each task along with subtasks, each treated as subevents. The analyst may cluster the subtasks together to indicate they belong to a single series of actions. By clustering is meant that the analyst may elect to list the subtasks as separate subevents but then group them together for coding efficiency. It is assumed that when subevents are clustered, they feature common characteristics and PSFs that do not warrant separate detailed coding as subevents. Only one Worksheet B is coded for the entire cluster.

Alternately, if the analyst is not interested in detailed task decomposition, he or she may elect high-level tasks corresponding to the main tasks, excluding the subtasks. These high level tasks correspond to the subevents in the timeline, without treating each subtask as a separate subevent. In other words, some subtasks may be purposefully omitted in order to provide a clearer timeline and avoid the need to cluster subevents.

Note: A priori clustering of subtasks as part of a single task or subevent is possible for simulator studies but not for event data. Clustering for simulator studies reflects the controlled nature of the study design. Event data must establish a clear performance pattern before being clustered. Because simulator studies typically represent carefully controlled scenarios, it is uniquely possible to cluster subtasks prior to data collection on the basis of shared scenario or situational characteristics.

3.2.3.2 Input of Data from Multiple Crews

Simulator data are usually the product of multiple crew runs over multiple scenarios, thus producing a wealth of data for possible inclusion in HERA. Consider the SGTR example, decomposed to the primary task level presented earlier. In a hypothetical study involving ten crews, all crews successfully detect and identify the SGTR, isolate the SG, cool down the RCS, and achieve pressure balance. However, one crew fails to depressurize the RCS in the prescribed time, while another crew initially fails to terminate the safety injection (but eventually recovers and achieves pressure balance, albeit at a significant delay compared to other crews).

This example reveals a particular nuance of efficiently coding simulator studies into HERA. It is possible to model the actions of each crew separately and generate ten separate timelines with corresponding Part B worksheets. This process would likely result in ten separate event entries, each with six subevents corresponding to the major tasks of interest in the SGTR. Without software assistance to duplicate event and subevent level information, coding would not be particularly parsimonious, because manually entering nearly identical data records would prove unduly repetitive, while attempts to extract meaning of the separate crew entries would likely prove problematic without careful cross-referencing between crews and scenarios.

HERA provides specific data fields that facilitate the categorization of simulator data. In the HERA Part A Worksheet, Section 1, Item 10, a box may be checked to denote that the data are part of a simulator study. Four text fields accompany the designation of a Simulator Study in Item 10:

- Experiment Information,
- Scenario,
- Variant, and
- Crew.

The *Experiment Information* field is used to provide a short description of the overall simulator study under investigation (e.g., “SGTR Complexity Study”). Each crew is treated as a separate event entry; it is the Experiment Information field that ties the different events together. Separate events that feature the same Experiment Information field are considered part of the same study. The *Scenario* field is used to delineate groups of experimental manipulations, as required. The overall study might, for example, feature two scenarios, corresponding to independent variables that are manipulated (e.g., “Basic SGTR” vs. “Complex SGTR”). Further variations of the scenarios would be featured in the *Variant* field (e.g., “Clear Indicators” vs. “Misleading Indicators”). Finally, the *Crew* field allows the analyst to record which crews correspond to each scenario and variant. Table 3.1 shows the concatenation of the levels of scenario and variant manipulations coupled with the crews tested in those scenarios.

Table 3.1 Example Simulator Study Scenario, Variant, and Crew Assignments

Experiment	**SGTR Complexity Study**		
Scenario	**Basic SGTR**	**Complex SGTR**	
Variant		**Clear Indicators**	**Misleading Indicators**
Crew	**1-10**	**1-5**	**6-10**

Note in the example that the scenario is a within-subject design, whereby all crews participated in both the “Basic SGTR” scenario and the “Complex SGTR” scenario. The two variants of the “Complex SGTR” scenario are a between-subject design, whereby different crews participated in different experimental conditions. According to the information in Table 3.1, the overall study would consist of three separate timelines, corresponding to the Scenario and Variant combinations. In other words, a separate set of Part A and corresponding Part B worksheets would be coded for each of the crews featured on the bottom line. The total number of events coded would be 20, corresponding to the ten crews in the “Basic SGTR” condition and the same ten crews in the “Complex SGTR” condition, five crews each for the “Clear Indicators” and “Misleading Indicators” scenario variants.

3.2.4 Simulator Study PSFs

As discussed earlier, it is crucial for the simulator study to be designed in such a way that it is possible to collect the PSF Details and PSFs required for HERA. In event reports, PSFs must be carefully weighed in the face of available reported data. Simulator studies afford the opportunity to collect all necessary data to assign the PSFs with a minimum of expert inference.

It is useful to review the three types of simulator and simulation PSFs discussed in Boring (2006). In an event or simulator study, PSFs may be considered *static conditions*, *dynamic progressions*, or *dynamic initiators* (see Table 3.2). These three PSF types are explained below:

Table 3.2 Types of PSFs to Consider in Simulator Studies

Static Condition	Dynamic Progression	Dynamic Initiator
PSFs remain constant across the events in a scenario.	*PSFs evolve across events in a scenario.*	*A sudden change in the scenario causes changes in the PSFs.*

- A *static condition* denotes a scenario or event in which the PSFs remain constant. An example of such a PSF in HERA is “Fitness for Duty / Fatigue.” Especially in the context of the relatively short duration of simulator study runs, there is typically little opportunity for fitness for duty or even the fatigue of the operators to degrade during the course of the study. Physical injury or sudden emotional stress are also ruled out as possible effects on the operators’ fitness for duty during the simulator run. Since this PSF is not expected to change during the simulator run, it is not necessary to monitor this PSF during the study. It is helpful to take an initial measure of this PSF or to assign it a known value based on the investigator’s expertise. Unless there are significant situational or contextual changes during a scenario (such as caused by a dynamic initiator), the following HERA PSFs may typically be considered static conditions: Experience & Training, Procedures & Reference Documents, Ergonomics & HMI, Fitness for Duty / Fatigue, Environment, and Team Dynamics / Characteristics. Communication may likely be static for a well-seasoned crew that has developed significant cohesion and that does not include new members.

  Note that each of these PSFs may, in fact, change dramatically throughout a scenario. An experienced and highly trained crew may encounter a novel situation for which they have minimal training and experience. Quality procedures may fail to cover an unusual or unexpected plant state. An overall effective HMI may suddenly give a misleading indicator. A fit operator may gradually become fatigued. Trusted systems in the environment such as lighting may fail. Otherwise stable team dynamics may prove forfeit in the face of particularly stressful and complex events. In a carefully controlled simulator study, such changes are most likely the result of the investigator’s manipulation of the scenario to trigger changes in the PSFs in order to measure the effects of these PSFs on human performance. See the discussion below on dynamic initiators.

- A *dynamic progression* encompasses those PSFs that naturally change and evolve across a scenario. These PSFs should be assessed or monitored regularly throughout the scenario to allow a mapping between the tasks (subevents) and PSFs. "Complexity" is an example of a PSF that is expected to change throughout the course of the scenario. As the scenario evolves, the operators are constantly required to monitor plant indicators and take appropriate actions. Simultaneous tasks, ambiguity, simultaneous alarms, and other factors combine to vary the situational complexity throughout the operation of the plant. The following HERA PSFs may generally be considered dynamic progressions: Available Time, Stress & Stressors, Complexity, and Communication.

  In some cases, it may be appropriate to treat static condition PSFs dynamically, especially in particularly dynamic scenarios. Note that static condition and dynamic progression are not mutually exclusive categories. The decision to treat a PSF as static or dynamic resides with the investigator or analyst and is a function of practical considerations in terms of the amount of recurring data collection that is required during the simulator study scenarios. The delineation provided here serves as general guidance that is applicable to most scenarios.

- A *dynamic initiator* occurs when any PSF is altered by a sudden change in the simulator study scenario. Almost any PSF, whether normally treated as static or dynamic, may respond to a sudden change in the scenario. Consequently, following the introduction of an experimental manipulation, it is useful to monitor the status of PSFs. For example, the introduction of a plant trip and the crew's entry into emergency operating procedures is expected to dramatically alter the crew's actions as well as their mental activities. The experimental manipulation instantly changes the operators' PSF states. For example, entry into an emergency operating procedure almost instantly changes the Available Time (e.g., may suddenly become limited), Stress & Stressors (e.g., may elevate), Complexity (e.g., may increase), Experience & Training (e.g., may not have covered the situation at hand), and Procedures & Reference Documents (e.g., may not fully address the situation). It may also alter Ergonomics & HMI (e.g., may be affected by situation), Work Processes (e.g., may highlight new facets not covered by other situations), Communication (e.g., may degrade), and Team Dynamics / Characteristics (e.g., may change in the face of an emergency situation). In some cases, the dynamic initiator cause may be attributed to a single PSF. For example, a sudden loss of instrumentation or lighting would apply to the Ergonomics & HMI and Environment PSFs, respectively, and would have an almost immediate trickle-down effect to other PSFs.

Those PSFs that are deemed static conditions may be determined at one point in the study and left constant across subevents, unless there is a dynamic initiator. The PSF details may also be determined at one point and left constant in the coding across subevents.

Note: It is not possible to assign static conditions for most event reports such as LERs and AITs. The static nature of PSFs results from the carefully controlled nature of control studies. In practice, of course, some PSFs found in event reports may prove static, but this can only be determined after careful assessment of the status of the PSF throughout the event. Static and dynamic PSFs are coded identically in the HERA worksheets. The difference between static and dynamic PSFs to the HERA analyst or the study investigator involves how often the PSFs are tracked and measured. Static PSFs are not typically tracked throughout the scenario; dynamic PSFs should be measured regularly and repeatedly.

3.3 Additional Simulator Study Coding Tips

The previous sections of this chapter outlined key considerations for capturing control room simulator study data into HERA. This section provides a walkthrough of considerations pertaining to completing each part of the HERA worksheets.

3.3.1 Worksheet A, Section 1 (Plant and Event Overview)

When a published summary of the simulator study is available, this should be cited in Items 1 and 2 on source documents. When no published summary is available, the cited source should denote the simulator name and date of study (e.g., “HAMMLAB Complexity Study, 2006, unpublished”).

To the extent appropriate, plant information should be captured in Items 3-5. This should indicate the plant type and conditions that were modeled in the simulator. The “Other” field should be used to denote the degree to which the simulator is congruent with the crew’s “native” plant control room. The less congruence there is, the more it is expected that the plant crew’s performance will deviate from performance norms. Additional remarks regarding the fidelity of the simulator and the relationship between the simulated and native control room should be noted in Section 2.

Event information should be captured in Items 6-9. This information only needs to be as complete as the underlying simulation. Where particular systems and functions are manipulated experimentally, these should be recorded. The time should be recorded in real time to reflect any time-of-day considerations that may be present during the simulator run.

As described previously, the essentials of the study design are recorded in Item 10. Each scenario or variant that requires a different crew will receive a separate Worksheet A and accompanying Part B Worksheets for the scenario tasks or subevents.

3.3.2 Worksheet A, Section 2 (Event Summary / Abstract)

Section 2 is designed to contain an event summary or abstract. From the perspective of recording the essential information of the simulator study, it is important that this section contains background information on the simulator type and configuration, including its similarity to the crew’s native control room; a clear expression of the purposes, hypotheses, and goals of the study; details regarding all experimental manipulations, including explanations of the scenarios and variants; a description of the crews who participated in the study; and a summary of study findings.

3.3.3 Worksheet A, Section 3 (Index of Subevents)

The Index of Subevents was discussed previously in this document. The coder should follow guidance found in Chapter 2 for classifying the work type, personnel, pre/during/post initiator, active/latent event, and error of omission/commission. Typically scenario tasks are treated as subevents in the timeline. Subtasks may be clustered under a common task and treated as clustered subevents. As suggested earlier, simulator data may often contain only successful human actions (HSs). Plant states and contextual information (i.e., EE, XEQ, EQA, PS, or CI) may also be included to the extent appropriate to capture the nuance of the scenario. Time should be recorded in real time, not as elapsed time since onset of the study.

3.3.4 Worksheet A, Section 4 (General Trends Across Subevents / Lessons Learned)

This section encompasses trends and lessons learned from the scenarios. The same guidance applies as when completing analyses from event reports.

Note: It should be remarked that these trends may not be causal in the same manner as for events. In many cases, the study investigator may manipulate factors to test human performance under adverse conditions. Thus, there is no implication of fault on the part of the crew or the plant. The only cause of the adverse conditions is the investigator's experimental manipulation.

3.3.5 Worksheet A, Section 5 (Human Subevent Dependency Table)

This section features the Human Subevent Dependency Table. This section may not be relevant to all simulator studies, especially for those simulator studies that have only positive human subevents (HSs) in their timeline. Recall that dependency is only indicated for XHEs. Dependency should be considered for all XHEs identified through simulator studies. If the dependency link between XHEs is caused by the experimental manipulation and not specifically by the links in crew performance, these should be clearly noted in the comments section. Simulator studies will typically involve the same crew performing actions close in time, which may be sufficient basis for assuming dependency. Analysts may also wish to consider the extent to which PSFs co-occur across subevents as additional criteria for establishing dependence.

3.3.6 Worksheet B, Section 1 (Personnel Involved in Subevent)

This section allows the HERA analyst to record the personnel who were involved in the scenario. Typical simulator configurations focus on control room crews only and do not include, for instance, auxiliary operators, engineering staff, etc. It is therefore expected that most simulator studies will only feature personnel found under the *Operations* heading.

3.3.7 Worksheet B, Section 2 (Contributory Plant Conditions)

This section handles conditions at the plant. The HERA analyst should note which plant conditions are manipulated in the simulator scenario as well as which plant functions, systems, and components would be affected by the experimental manipulations.

3.3.8 Worksheet B, Sections 3 and 4 (Positive and Negative PSF Details)

Positive and negative contributory factors or PSF details call for expert knowledge about the interaction between the study scenarios, plant conditions, and the operators. As with PSFs, PSF details may be considered static or dynamic and may be treated appropriately. For static condition PSFs, it is typically sufficient for the study investigator and plant operations expert to evaluate the PSF details once across all conditions and for all crews. For dynamic progression and dynamic initiator PSFs, details should be recorded across scenarios for each crew.

It is useful to have an operations specialist who is trained on HERA definitions observe the live or recorded simulator runs for each crew and make expert ratings about the PSF details. It is possible to provide the observer an abridged HERA worksheet that only encompasses those PSF details deemed to be dynamic throughout the scenario.

3.3.9 Worksheet B, Section 5 (PSFs)

In HERA analyses based on event reports, the PSF details serve as the basis for identifying a PSF. This basis also applies to simulator study analyses, but the PSF details are not the only possible basis for the assignment of a particular PSF. The simulator study has additional detail available that may serve as evidence for the influence of a particular PSF. For example, subjective ratings on PSFs by the crew and by expert observers may indicate the state of a PSF. Also, objective measures such as performance criteria, physiological measures, and simulator logs may indicate the influence of a particular PSF. These information sources augment the PSF details and should also be considered in the overall determination of PSF assignment levels. The overall use of such measures should be documented in the summary in Part A, Section 2. The specific metrics used to establish a particular PSF should be fully documented in the comments section of that PSF.

3.3.10 Worksheet B, Section 6 (Human Cognition)

Aspects of human cognition such as detection, interpretation, planning, and action are recorded in this section. An analyst may wish to delineate overall tasks according to the constituent subtasks for the purposes of completing this section (e.g., a particular task may have subtasks separately related to detection vs. action, which may be treated as separate subevents). The analyst should exercise expert judgment in the classification of the cognitive steps involved in each scenario task.

3.3.11 Worksheet B, Section 7 (Error Type)

This section denotes the error type and should be assessed for each crew and subevent according to the guidance in Chapter 2. Note that across crews, for the same subevent, it may be possible that some crews succeeded (an HS subevent), while some crews did not meet the success criteria (an XHE subevent). This section should only be completed for those crews for which the subevent is classified as an XHE.

3.3.12 Worksheet B, Section 8 (Subevent Comments)

In this final section for general subevent comments, it is useful to paraphrase the overall performance findings of the task, particularly when crews differed from expected performance. Any manipulated PSFs or other causal factors should be noted here as well.

3.4 HERA Coding for Non-Optimized Simulator Studies

The preceding discussion has focused on coding HERA for simulator studies that are optimized to HERA's data collection needs, particularly in terms of the collection of data for a full suite of PSF data. Of course, many simulator studies are not optimized to HERA, particularly with regard to the extensive PSF information required to complete the HERA coding. It is nonetheless possible to use the data from such studies. When using such data, it is important to note in the overall event summary (Worksheet A, Section 2) what measures were available in the study that helped complete the HERA analysis. Equally important, the data that were not available (such as PSF information that were not recorded in the study) should be noted. For unavailable data, fields denoting “not applicable” or “insufficient information” should be used.

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4 HERA QUALITY ASSURANCE PROCESS

4.1 Introduction

This chapter discusses the process for implementing quality assurance (QA) for the HERA data collection process. The ultimate goal of the QA process is to ensure that the data that are collected and processed in HERA are *fault free*, *valid*, and *reliable*. *Fault free* refers to the data integrity, while *valid* and *reliable* refer to the data content. This chapter addresses ways to ensure valid and reliable data coding. The initial sections of this chapter highlight QA processes specific to extracting data from event reports. A concluding section discusses QA with respect to control room simulator studies. *Valid* means that the data in HERA capture the aspects of human subevents that actually occurred in an operating event. *Reliable* refers to consistency within an individual HERA analyst as well as consistency between HERA analysts. Consistency within a single HERA analyst is comparable to *intra-rater* reliability and refers to the aspects of the QA process that would help the individual HERA analyst code the same event in the same manner, time after time. Consistency between HERA analysts refers to *inter-rater* reliability, meaning the QA process ensures two or more HERA analysts arrive at the same conclusions and coding of a given human subevent, time after time.

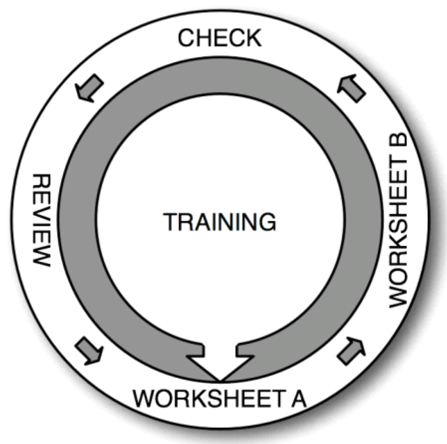

Figure 4.1 Quality Assurance Process in HERA

The recommended QA process for HERA entails five stages of checks and best practices for facilitating valid and reliable data content (Figure 4.1). This includes initial training and methods of assuring quality at each step of the event analysis. These methods include best practices and guidelines for event coding of Worksheets A and B, a clerical consistency check, and an external review. These steps are explained in detail in the following sections.

It is the goal of this QA process to ensure HERA data validity and reliability, but there are times when the recommended process can prove too rigid for project requirements or circumstances, or when limitations in personnel availability require a modified coding team configuration. To address this issue and allow for flexibility in coding team configuration and analysis cycle, this chapter will:

- Detail the minimum requirements for maintaining acceptable data quality levels at each step in the analysis process
- Recommend the optimal method of assuring quality at each step in the analysis process

4.2 QA Stage 1: Coding Team Qualifications and Training

The HERA analysis process requires human factors, HRA, and operations experience in order to appropriately understand and interpret an event. The goal of training is to emphasize not only fundamental skills but also awareness of quality processes. In section 2.2 above, the specific skill sets necessary for the HERA analysis process are presented as:

Human Factors (HF) and HRA

- Knowledge of human performance fundamentals (e.g., human cognition, PSFs, and organizational influences on behavior)
- Knowledge of human factors issues as they relate to the design and operation of nuclear power facilities
- Knowledge of HRA issues and methods (e.g., SPAR-H (Gertman, et al, 2005), ATHEANA (Cooper, et al, 1996), *Good Practices for Implementing HRA* (Kolaczkowski, et al, 2005)) and an understanding of how HRA fits into the PRA process
- Experience with and a basic understanding of nuclear power plant operating experience and event reports
- Basic understanding of plant physics, chemistry, thermal-hydraulics, and nuclear science is very helpful

Operations (OPS)

- Knowledge of nuclear power plant systems, equipment, function, procedures, and operation (e.g., a former operator, NRC inspector, etc.)
- Knowledge of PRA, HRA, and current methods and models (e.g., Standardized Plant Analysis Risk (SPAR)).

As discussed above, two analysts are required at a minimum for the HERA analysis process, because the QA process relies upon the collaboration between two analysts. Typically, one analyst will have HF and HRA experience, and the other will have operations expertise. Additional team members are recommended and will be discussed below.

This section lists more specific requirements and recommendations for providing analysts with the required experience.

To ensure a minimum quality of data, it is important that the HERA analyst with HF/HRA experience has college level experience in a human performance or related field, such as psychology, human factors, or cognitive science.

The analyst with operations experience should have an interest in root cause analysis and identifying and analyzing human actions in events of interest to HERA analysis. It is also important that the operations expert have a willingness to provide impromptu and planned tutorials on the principles of plant operations, plant characteristics and dynamics that aid other team members in understanding the plant subevents being analyzed.

Both analysts should have a willingness to explain their assumptions and reasoning regarding an analysis, and both should be aware of the limitations of their personal knowledge and be willing to seek additional information from other knowledgeable sources when needed.

Analysts also require adequate background training on error identification. The correct categorization of plant events into system (e.g., equipment) failures and human failures and successful actions as well as the identification and classification of PSFs and event dependencies require proficiency in HRA as well as calibration of the analyst to a baseline of accuracy and consistency with other analysts.

Prior exposure to and experience in HRA in both analysts is a considerable asset, but does not preclude the necessity of specific training on the HERA analysis process. Training requirements can, however, be decreased significantly when the HERA analyst has prior HRA and plant operations experience that is equivalent to or otherwise encompasses that covered below, or when the topic of HERA analysis is focused on a specific domain that does not require the breadth of training prescribed here. Decreases in training requirements should be evaluated on a case-by-case basis.

Training can make use of readily available HRA training tools. The training materials may include:

- A thorough examination of the nature of human error is provided in *Human Error* (Reason, 1990). Reason also provides a valuable discussion of organizational impacts on human performance in *Managing the Risks of Organizational Accidents* (Reason, 1997). It is advised that all analysts on the HERA coding team read both of these books.
- A review of the HRA course developed for the NRC Office of Nuclear Regulatory Research. This is a three and a half day course, and the course material is available in PowerPoint from the NRC. The materials in the course directly supplement the textbook, *Human Reliability & Safety Analysis Handbook*, (Gertman & Blackman, 1994), which should be read in conjunction with the course materials. This course includes training on human error identification, and a retrospective human factors analysis of the 1999 JCO criticality accident.
- HERA analysts benefit from a thorough review of HRA methods such as SPAR-H (NUREG/CR-6883; Gertman et al, 2005), ATHEANA (NUREG-1624, Rev. 1; Barriere et al., 2000), CREAM (Hollnagel, 1998), and THERP (NUREG/CR-1278; Swain and Guttman, 1983), as well as an understanding of the *Good Practices for Implementing Human Reliability Analysis* (NUREG-1792, Kolaczkowski et al., 2005), and the International Atomic Energy Agency (IAEA) human factors classification system (IAEA-J4-CD-10). Reading and understanding these HRA methods is recommended to facilitate HERA data entry. Specific HRA training in the above methods or other methods is recommended, when available.
- To understand the event categorization used in HERA, the analyst should review the related *Human Performance Characterization in the Reactor Oversight Process* (NUREG/CR-6775; Gertman et al., 2002). Similarly, The analyst should review the current HERA volume as well as the HERA NUREG/CR-6903 Volume 1 (Hallbert et al., 2006).
- For the types of human failure and success events that will be encountered in a nuclear power plant setting, the analysts are recommended to read the *Review of Findings for Human Performance Contribution to Risk in Operating Events* (NUREG/CR-6753; Gertman et al., 2002).
- A final aspect of training is an overview of event analysis followed by hands-on experience performing event analysis in HERA. The goal of this training is to allow the new analysts to gain proficiency in the HERA process and in the mechanics of performing HERA data entry. Throughout the sample analyses, the analyst will consult with members of the HERA analysis team and review his or her analyses. Specific areas of agreement and disagreement between the HERA entries will be discussed and consensus reached on coding strategies.

4.3 QA Stage 2: Worksheet A Coding

The coding of events into HERA is described in Chapter 2 of this document. Analysts' experiences with coding HERA events have identified several best practices for completing Worksheet A, including:

- *A team approach to QA:* The two HERA analysts review the data source(s) and then discuss the analysis to ensure acceptable inter-rater reliability. The analysts should preferably be comprised of a mix of HRA and plant operations experience.
- *Multiple readings of the source material:* In order to extract the maximum level of detail that is possible, the two HERA analysts read the source materials more than once. Prior experience reveals that a single reading of an information source is rarely sufficient to extract the detail necessary for HERA. Likewise, it is crucial to obtain data sources that provide a rich enough description of the event or study to afford meaningful data extraction into HERA. For example, an LER will invariably provide less detail than an AIT report; it is therefore preferable to use AIT reports for extracting data over LERs when available, unless time or other constraints prohibit the use of the detailed data source (see Section 4.7 in this volume for additional considerations on data sources and data quality).
- *Construction of an event timeline prior to coding:* After a thorough review of available data sources is conducted and a mutual understanding of the details surrounding the information to be captured is achieved, one analyst prepares an initial outline of human and system subevents. The second analyst reviews the timeline for completeness and accuracy of details. Optionally, the two analysts may develop the timeline together. In concert, the analysts finalize the timeline.
- Plant and Event Overview (Worksheet A, Section 1) completion: The plant background information is most appropriately characterized in HERA by an analyst with plant operations expertise.
- *Translation of the event timeline into the Index of Subevents (Worksheet A, Section 3):* Once the initial event timeline is agreed upon, the analysts together complete the Index of Subevents. This process is considered a strict consensus effort, since all Worksheet B coding hinges on the information outlined in this section. Any points of discussion should be recorded in the Comments fields. Particular care should be taken to ensure that subevents are clustered appropriately.
- *Team consideration of dependency between subevents:* The Human Subevent Dependency Table (Part A, Section 5) should be considered and completed together by the analysts. Factors affecting dependency should be carefully noted.
- *Trending across subevents (Part A, Section 4):* The analysts should discuss general trends and lessons learned from the event coding after completing the Index of Subevents and again after completing the Part B Worksheets. Initial impressions should be captured during the first discussion, which should be checked and confirmed after completion of all analyses. The purpose of the pre- and post-analysis trending is that the initial coding may indeed identify the most salient aspects of the analysis—aspects that may be overshadowed by less consequential nuances in coding the detailed worksheets in Part B. By identifying first impressions, the analysts are able to check their assumptions throughout the process of coding the Part B Worksheets. It is important then to revisit these assumptions later in the face of the detailed analyses conducted across subevents.
- *Revision to timeline as needed:* When appropriate as a result of the availability of new data sources or additional insights into the analysis afforded through performance of the Worksheet B coding, the analysts will meet to discuss and finalize revisions to the Index of Subevents (Worksheet A, Section 3).

Upon completion of Worksheet A and any Part B worksheets, both analysts sign off on the coding to signify completion of the coding.

4.4 QA Stage 3: Worksheet B Coding

The process for coding Worksheet B is similar to that of Worksheet A, involving the team of analysts. However, when completing Worksheet B, the coding may be completed by one analyst (typically the analyst with the strongest HF/HRA background) with a subsequent thorough review by the other analyst. Special considerations for this stage of coding include:

- *Initial coding by one analyst:* Upon establishment of the timeline in QA Stage 2, the analyst individually completes Worksheet B for each human subevent identified in Worksheet A to receive Worksheet B coding. The analyst will consult frequently with the other analyst, particularly with regard to assigning appropriate PSF details and levels.
- *Full documentation of all sources of information:* This includes specific reference to the document source(s) used to derive a particular PSF detail or level assignment.
- *Documentation of all subjective judgments:* All judgments and PSF assignments that are not explicitly derived from the source material (e.g., an LER) should be fully documented as inferential.
- *Review by second analyst:* A second analyst will review PSF assignments and the documented justification of those assignments for accuracy. If there are significant areas for revision, the second analyst may address these him- or herself directly in the database or ask the original analyst to revise the analysis. The analysts work together iteratively to arrive at agreed-upon assignments. Any disagreement on coding should be noted in the appropriate comments fields.
- Revision of timeline as appropriate: Worksheet B coding represents a thorough analysis of subevents. Occasionally, in the course of this analysis, the analysts may observe the need for revision to the Index of Subevents in Worksheet A. It may be discovered that subevents can be clustered or that additional subevents are necessary to explicate the evolution of the event. Such changes should be discussed between the analysts and incorporated into Worksheet A.

Optionally, both analysts may complete the Worksheet B coding together.

Once both analysts have reviewed the HERA analysis, they sign off on the analysis in the HERA database or on the HERA worksheets, such that the event coding will be considered complete, pending clerical consistency checking.

4.5 QA Stage 4: Clerical Consistency Check

People are prone to make errors during data entry, especially when those data are transcribed from other sources of information such as paper forms or digital versions of LERs. The clerical consistency check serves as a “second check” to ensure that the HERA analysis accurately reflects the analysts’ intentions.

At a minimum, both analysts should always check their work while encoding the analysis. Key areas to check include:

- Correct source data header information (e.g., correct plant name, correct LER number, and correct plant power state determination).
- Accuracy of the timeline (e.g., correct dates and times, and no missing or repeated subevents in the timeline).
- Completion of the correct HERA analysis worksheets (e.g., completion of Part B Worksheets for all relevant human subevents).
- Accuracy of forms (e.g., no missing PSF assignments and no assignments without documentation).
- Correct spelling (i.e., no obvious misspellings in the HERA database).

In addition to the analysts' self-check, it is recommended that an additional checker be enlisted, typically someone else with HF/HRA or operations experience. At a minimum, the second checker will perform a clerical review of the complete analysis.

The second checker also may review the data encoding for correct source data header information, accuracy of the timeline, completion of correct HERA worksheets, accuracy of the forms, and correct spelling. In such cases, the analysts should provide the second checker with all source materials as well as any paper analyses, calculations, or notes that were generated during the analysis. The second checker makes changes directly into the database or provides comments to the analysts. Should the checker discover areas where there are significant errors (e.g., a required worksheet is missing), the analysts are consulted for correction.

If the second checker disagrees with any human subevent analysis assignments such as PSF rating, the analysts are consulted for clarification and consensus. In the event that the analysts and second checker do not reach consensus, the assignments should be reviewed by additional personnel to determine the appropriate analysis assignments.

Before the analysis is handed off for external review, HERA records the second checker sign-off on the analysis, indicating successful completion of the clerical consistency check.

4.6 QA Stage 5: External Review

For analyses that will be included in the HERA database, an external review is required. For other users who will not be submitting analyses to the HERA database, an external review is strongly recommended, but not required. The following discussion presumes that the analyses will be included in the HERA database.

Upon completion of HERA event coding by the analysts, followed by the clerical consistency check, the event coding must be externally reviewed. The external review is typically performed by an NRC staff member or subcontractor. This individual is qualified with extensive expertise in the field of HRA methods as well as appropriate experience performing HRA for nuclear power scenarios, or with extensive PRA knowledge and plant operations experience.

The extent of review is determined by the type of event or data encoded as well as the risk significance of the event. QA, as it pertains to the external review, entails the following:

- Minimal review of source materials. The reviewer will read excerpts from the source material, but it is generally not expected that he or she will read the entire source material. The purpose of the external review is in part to ensure that the analysis is self-explanatory without the need for extensive review of all available source materials.

- Timeline review. The reviewer will read through the event timeline and construct a mental overview of the progression of subevents. This progression should provide sufficient detail so that the event can be reconstructed. The characterization of subevents according to the subevent codes should be logical and self-explanatory. The dependency between subevents should be clear.
- PSF review. The reviewer will appraise PSF assignments and the documented justification of those assignments for accuracy.

If there are significant areas for revision, the reviewer may gather clarification from the HERA analysts and ask the analysts to revise the coding. Once complete, revisions are returned to the reviewer. When the external reviewer is satisfied with the analysis, he or she notes approval in the HERA database. At this point, the event coding is considered a completed record and is included in the releasable versions of the database.

4.7 Special Considerations

4.7.1 Special Considerations on Data Quality

HERA analysts have revealed that one common source of analysis uncertainty is in arriving at the proper rating or details for the PSFs. This uncertainty stems largely from the fact that much of the information about the PSFs is derived from a thorough understanding of plant operations related to the event, and this level of detail is not typically provided in LERs, for example. An LER does not, for example, report that an operator may experience increased stress when entering an emergency operating procedure; nor does an LER typically report ergonomic features of a particular control room's instrumentation. The purpose of the LER is for the licensee to report, in condensed form, the primary factors contributing to an event. More often than not, LERs provide only limited insights on human performance that are critical to completing an HRA. In LERs, it is much more common simply to report that an operator failed to operate a control properly than to itemize the underlying contributors to the operator's error. In conducting an analysis using an information-poor data source, analysts have three potential choices: deferring to operational knowledge from an operations expert, finding additional sources of information, or indicating that insufficient information is present in the source material.

When sufficient human performance information is provided in the source document, there is a high fidelity in the resulting PSF assignments. When little or no human performance detail is provided, there is a margin of uncertainty in the resulting PSF assignments. A plant operations expert provides his or her best approximations for the contributing factors based on contextual information provided in the source document and the analyst's general plant operations experience.

Thus, determining the proper details for PSF assignments requires a certain amount of insight and plant operations acumen. A complete analysis of an event would usually entail a series of interviews with plant personnel to arrive at the general context of the event as well as the specific human contributions to that event. Without the luxury of interviewing involved plant personnel, the HERA analysts must arrive at this information through other means.

A chief resource is an available plant operations specialist, who has enough experience to estimate the probable factors affecting human performance of an event. Even so, a plant operations specialist may not always be able to glean enough information from the LER or other source to determine a complete set of PSFs and details. Without explicit details of the PSFs in an event, the plant operations specialist must arrive at general factors. The coding in the HERA database necessarily reflects the general experience of the plant operations specialist and may not always be a plant or event specific reflection of the PSFs. Analysts should denote insufficient information for PSFs in the absence of plant specific information.

When insufficient information is available in an LER or other incident reports, the analysts may wish to obtain additional sources of information, such as root cause investigation reports, for example. However, use of additional information generally increases the time required to complete the HERA analysis.

4.7.2 Special Considerations on Documenting the HERA Analysis

A crucial component of the HERA QA process is the inclusion of documentation and Comment fields. The analysts, when inputting data into HERA, always documents the process, including sources of information and inferences that were made. Although it may not always be possible to review plant specific procedures, when evaluating any procedures that contributed to an event, the specific procedures should be indicated. This information would typically include the number, section, and subsection for emergency, annunciator, or standard operating procedures. Similarly, the analysts should indicate any pertinent information available on indicators and displays. This information should be noted under the Ergonomics/HMI PSF and should be reflected in the selection of the weighting for that PSF. If the analysts refer to external sources of information such as event or plant databases or operations experts, these sources should likewise be noted in the database.

The analysts should document the level of human performance detail provided in the source(s) of information. When there is explicit information in the source about the contributing PSFs, the subevent should be documented with reference to the source. When the information is not explicitly contained in the source and must be derived from context and previous operations experience, the subevent should be documented as “Inferred.” This distinction is aimed at helping the end user of HERA determine the extent to which the PSFs assignments and details can be verified.

It should be noted that the use of PSF details that are explicated in the source is not always a guarantee of their truthfulness or completeness. It is, for example, at the discretion of the licensee which human performance factors are mentioned in the LER or other incident report. Those human performance factors that the licensee includes may not always be complete. In some cases, the HERA analysts may supplement or clarify those PSF details provided in the source, especially when the human performance information is incomplete. This information should always be noted in the accompanying comment field in the HERA database.

4.7.3 Special Considerations on Selecting the Data Source

As outlined in Volume 1 of this NUREG/CR-6903, there may be many available sources of information on human subevents. The decision of which sources to use is the task of the project manager. It is recommended that whenever possible, multiple sources of information should be consulted. The quality, validity, and reliability of the analysis will generally be higher when multiple sources for the same event are consulted. Any additional sources should, of course, be noted in HERA and accompany each data record.

4.8 QA Process Guidelines for a Compressed Analysis Cycle

The recommended QA process outlined in this chapter may prove especially time consuming because it enlists the joint expertise of multiple analysts in serial fashion. Each analyst—whether the two HERA analysts, the second-checker, or the external reviewer—is allowed sufficient time to review the HERA analysis and make appropriate modifications. Further, the process of cross-validating information from multiple sources is particularly time-consuming for the analysts.

There are times when it is necessary or desirable to conduct a compressed analysis cycle in HERA. In such cases, there are shortcuts to the data analysis process that include the most essential features of the QA process while emphasizing the need for expedient data analysis. Specific shortcuts are possible at most levels of the QA process and include:

- *Training.* As noted earlier, the training requirements to achieve proficiency in HERA can be shortened considerably when the prospective HERA analyst has adequate prior exposure and experience in HRA methods or when the HERA analysis scope is focused on a particular domain. It is expected that the HERA team will review training requirements for each potential HERA analyst based on that individual's background and the topical focus of the data analysis.
- *Worksheet Coding.* Two recommendations are provided for optimizing data coding by the HERA analyst:
    1. *Restrict the amount of source material that is used in the analysis of an event.* This has implications in terms of a speed-accuracy tradeoff—the richer the sources of information that are used, the higher the quality of the analysis. But, in cases where it is important to maintain a certain data analysis throughput, it is an acceptable compromise to opt for fewer sources of information in order to compress the analysis cycle.
    2. *Rely strictly on the information that is explicitly detailed in the data source.* By minimizing inferences and expert judgments about situational contributors to an event, the event analysis becomes a mirror of the information that is or isn't contained in the data source. This approach to coding results in fewer catalogued PSFs in favor of assignments as "insufficient information available."
- *Clerical Consistency Check.* The primary way to optimize the clerical consistency check is for the analysts to rely solely on self-checking. While a second checker is eliminated, the process does not forego checking, instead relying on a clerical self-check by the analysts. Self-checking risks retaining more clerical errors than would be present if the event were double-checked by a second party, but, in many cases, this will prove to be a reasonable tradeoff for compressing the analysis cycle.
- *External Review.* The HERA external review can be abbreviated in three important ways:
    1. *Focus the review of each event on the Index of Subevents.* The quality of this timeline—including the clarity of the subevent descriptions and classifications—shapes the subsequent quality of subevent coding in the Part B worksheets. Quality deficiencies in the timeline may bespeak quality deficiencies in the remaining coding. As such, a review of the timeline serves as a quick and useful QA screening tool.
    2. *Employ random or systematic sampling.* Rather than reviewing all events submitted for external review, the external reviewer may sample a subset of events and perform a thorough review only on those events. It is important that such sampling reflect each HERA analysis team with approximately equal frequency. For example, if there are two teams of HERA analysts and it is decided that every second event coded in HERA will be externally reviewed, it is important that every second event coded by *each* team be

considered. Each team should be considered independently when establishing a sampling rate. Otherwise, if one team is more prolific at coding than the other team, a sampling of every second HERA event coded could result in more frequent sampling of the prolific team, potentially skipping a review of the slower team.
    3. *The external reviewer meet with the analyst team.* This would permit the analysts to walk through the worksheets with the reviewer, allowing questions, discussion, and changes to occur real-time. This would likely reduce the calendar time required for an external review.
- *Review Scheduling.* It is not necessary for the clerical check and the external review to be performed in a particular order. They can be performed by separate individuals in parallel. Comments from the clerical check and the external review must be incorporated into the worksheets prior to submission to the HERA database, but the separate reviews do not have to be performed in a serial manner. This would likely reduce the calendar time required for the review/check process.

Further shortcuts are not recommended for the various phases of the HERA QA. The remaining functions are a central part of any HERA analysis and are essential to ensuring coding validity and reliability.

Caution is strongly advised when implementing any shortcuts to the HERA QA process. The consequence of an abridged QA process should not be the abandonment of maintaining quality in data coding. Instead, the goal of QA shortcuts should be to reduce inefficiencies in the process while maintaining acceptable levels of coding validity and coder reliability.

4.9 QA Process Guidelines for Simulator Studies

Many of the QA processes outlined earlier in this chapter regarding event report coding apply equally to the extraction of data from simulator studies. Analysts should have proper training to understand and complete the HERA coding; analysts (potentially including the study investigator) should work together to complete the analysis and second-check the coding; it is important for the coding related to the simulator study to be externally reviewed. A key difference between simulator studies and event reports, however, is that a large part of QA in coding simulator studies takes place in the design and conduct of the study–before the study is actually coded into HERA. Important pre-coding considerations include:

- Design of the study to capture the data fields necessary for HERA. It is especially important to develop suitable measures that correspond to the HERA PSFs and PSF details. These measures should ideally not rely solely on observer judgment or crew self-assessment, which may fail to capture the true range of human performance due to inherent human scaling biases (Poulton, 1989). Objective measures should be employed whenever practicable.
- Maximize the congruence between the crew's native control room and the control room simulator used in the study. A failure to utilize a close approximation can result in poor crew performance (due to a lack of experience and familiarity with the novel control room) and poor study generalizability. When differences between the simulator and the native control room plant are present, it is advisable to provide training to the crew on the novel control room prior to testing in the study. To avoid fatigue as a factor on performance, training and testing should not be conducted back-to-back.

- Develop clear criteria for successful crew performance on each task. Establishing clear success criteria facilitates coding of the crews' performance enables easier eventual comparison across crews once data have been collected.
- Ensure complete and accurate data gathering during the simulator runs. The integrity of data collection tools and the utility of observer judgments and subjective ratings should be pre-tested and reviewed during the course of simulator runs. A performance measure that fails to gather data in the intended way can compromise the completeness of the HERA analysis.

During the extraction of simulator data into HERA, the HERA analyst should work closely with the study investigator to ensure the quality of the data input. Instead of two analysts working in tandem, the investigator should assume a prominent role alongside the analyst. The investigator is the main resource for constructing the event timeline, cross-referencing findings across crews, and determining PSF data from the study. When the study investigator is not available with coding, two or more analysts should work closely together in the construction of the timeline and the extraction of PSF data according to the general QA guidance offered in this chapter.

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APPENDIX A HERA WORKSHEET A

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Human Event Repository & Analysis (HERA) Worksheet, Part A

Analyst 1:	**Analyst 2**:	**Reviewer 1**:	**Reviewer 2**:
Date:	**Date:**	**Date:**	**Date:**

Section 1: Plant and Event Overview

Document identifying plant and event information.

1. Primary Source Document: ___
2. Other Source Document(s): ___
3. Plant Name: ___
4. Plant Type: ☐BWR ☐PWR ☐Other: ___
5. Plant Operating Mode: ___

5a. Plant Power Level: ___

6. Event Type:
   Initiating Event: ☐Yes ☐No
   Common Cause: ☐Yes ☐No

6a. Event Date / Time: ___

6b. Event Description: ___

7. Affected Function(s): ___
8. Affected System(s): ___
9. Affected Component(s): ___
10. Source:
    ☐ LER
    ☐ ASP Analysis
    CCDP / ΔCDP: ___
    ☐ AIT
    ☐ Other ___
    ☐ Simulator Study
    Experiment Information: ___
    Scenario: ___
    Variant: ___
    Crew: ___
11. Similar to other events: ☐Yes ☐No

Comment: ___

Section 2: Event Summary / Abstract

Write a brief summary of the event, or copy in the event abstract. Discuss aspects of the event that are important from a HRA perspective. See Coding Manual for guidance.

___

Section 3: Index of Subevents

Provide a brief description of all subevents as well as subevent codes (XHE, HS, EE, XEQ, EQA, PS, or CI), date and time, work type and personnel involved (for all human subevents; see manual for codes), whether the subevent was pre-initiator (PRE), initiator (INIT), or post-initiator (POST), whether the subevent was active (A) or latent (L),and, if the subevent is an XHE, if it was an error of omission (O) or commission (C) or indeterminate (I). Indicate the Human Action Category number for XHEs and HSs (see manual), indicate whether a HS is a recovery, indicate whether the XHE or HS receives Worksheet B coding, list any related subevents, both prior and following the subevent, any comments (e.g., why a subevent is not receiving Worksheet B coding, contributing performance shaping factors), and whether the subevent will be included on the graphical timeline. See the coding manual for guidance on subevent breakdown and subevent code assignment. Use additional sheets as necessary.

Subevent Code	Date / Time	Work Type	Personnel	Pre / Initiator / Post	Latent / Active	Omission / Commission	Description	Human Action Category	Recovery	Worksheet B	Related Subevents	Comments	Graph
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐
									☐	☐			☐

Section 4: General Trends Across Subevents / Lessons Learned

Part A: General Trends ☐ Not Applicable

Indicate any strong, overarching trends or context across the subevents and provide a detailed explanation. This section is optional and only used when an issue is seen repeatedly throughout the event, to highlight the trend that may not be readily evident from the separate Worksheet B coding.

Trend	Comment
☐ Procedures (e.g., repeated failure to use or follow procedures)	
☐ Workarounds (e.g., cultural acceptance of workarounds contributes to multiple subevents)	
☐ Strong mismatch (e.g., between operator expectations compared to evolving plant conditions; between communications goals compared to practice; between complexity and speed of event compared to training and procedural support; between operator mental model and actual event progression)	
☐ Deviation from previously analyzed or trained scenarios	
☐ Extreme or unusual conditions	
☐ Strong pre-existing conditions	
☐ Misleading or wrong information, such as plant indicators or procedures	
☐ Information rejected or ignored	
☐ Multiple hardware failures	
☐ Work transitions in progress	
☐ Focus on production over safety	
☐ Configuration management failures including drawings and tech specs, such as incorrect room penetrations, piping or equipment configurations	
☐ Failure in communication or resource allocation	
☐ Other: ___	

Part B: Lessons Learned ☐ Not Applicable

Explain any key lessons learned from this event and / or any key corrective actions taken as a result of this event.

___

Section 5: Human Subevent Dependency Table

Place only the XHEs that receive Worksheet B coding on the top row and in the left column of the pyramid table. Check the appropriate boxes to indicate dependency between subevents. See the coding manual for guidance on assigning dependency. Provide explanation in the Comment table below to explain the factors that caused the subevents to exhibit dependency. Common dependency factors are listed in the pyramid table. Use additional sheets as necessary.

Subevent Code															
		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
				☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
						☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
							☐	☐	☐	☐	☐	☐	☐	☐	☐
								☐	☐	☐	☐	☐	☐	☐	☐
									☐	☐	☐	☐	☐	☐	☐
										☐	☐	☐	☐	☐	☐
											☐	☐	☐	☐	☐
												☐	☐	☐	☐
													☐	☐	☐
														☐	☐
															☐

Common Dependency Factors:

- Similar task
- Same person/people
- Close in time
- Same location/same equipment
- No independent oversight
- Same cues
- Action prompts next incorrect action
- Similar environmental conditions
- Unreliable system feedback
- Prior human failures on same equipment
- Lack of intervening human successes
- Cultural dependency
- Mindset
- Same work practices
- Other (explain)

Row Subevent Code	Column Subevent Code	Affects >1 subsequent subevent	Comment
		☐	
		☐	
		☐	
		☐	
		☐	
		☐	

APPENDIX B HERA WORKSHEET B

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Human Event Repository & Analysis (HERA) Worksheet, Part B

Source Document: ___ Subevent Code: ___
Description:

Section 1: Personnel Involved in Subevent

Indicate which personnel were involved in the subevent. Check all that apply.

☐ Operations (OPS)	☐ Plant Support Personnel	☐ Security
☐ OPS Supervisors	☐ Administrative Support	☐ Training
☐ Control Room (CR) Operators	☐ Chemistry	☐ Shipping / Transportation
☐ Outside of CR Operators	☐ Emergency Planning / Response	☐ Specialized Task Force
☐ Technical Support Center (TSC)	☐ Engineering	☐ Work Control
☐ Maintenance and Testing	☐ Fitness for Duty	☐ Licensing / Regulatory Affairs
☐ Maintenance Supervision / Planning	☐ Fuel Handling	☐ Non-Plant Personnel
☐ Mechanical	☐ Health Physics	☐ Contractor
☐ Electrical	☐ Procedure Writers	☐ Manufacturer
☐ I&C	☐ QA / Oversight	☐ NRC / Regulator
☐ Management	☐ Site-Wide	☐ Vendor
☐ Other: ___		

Section 2: Plant Conditions

Part A: Contributing Plant Conditions

Indicate plant conditions that contribute to this subevent, and / or influence the decisions and / or actions of personnel. Leave a detailed comment, with reference to the source document.

Plant Condition	Comment
☐ Equipment installed does not meet all codes / requirements	
☐ Manufacturer fabrication / construction inadequate	
☐ Specifications provided by manufacturer inadequate	
☐ Documents, drawings, information, etc., provided by the manufacturer incorrect or inadequate	
☐ Substitute parts / material used do not meet specifications	
☐ Material used inadequate	
☐ QA requirements not used or met during procurement process	
☐ Post-procurement requirements not used / performed	
☐ Lack of proper tools / materials	
☐ Installation workmanship inadequate	
☐ Equipment failure / malfunction	
☐ System / train / equipment unavailable	
☐ Instrumentation problems / inaccuracies	
☐ Control problems	
☐ Plant / equipment not in a normal state	
☐ Plant transitioning between power modes	
☐ Loss of electrical power	
☐ Reactor scram / plant transient	

Plant Condition	Comment
☐ Fire	
☐ Other: ___	
☐ None / Not Applicable / Indeterminate	

Part B: Effects on Plant ☐ Check to Exclude

Indicate the effects of this subevent on the plant.

1. Affected Function(s): ___
2. Affected System(s): ___
3. Affected Component(s): ___

Section 3: Positive Contributory Factors / PSF Details

Indicate any positive factors beyond what is nominally expected that contributed to the subevent. Check all that apply; if no details apply for a PSF category, check None. Indicate whether the detail is selected based on evidence directly from the source or if it is coder inference. Leave a detailed comment, with reference to the source document. This information is used to determine the Performance Shaping Factor (PSF) level in Section 5. This table continues on the next page.

PSF	Positive Contributory Factor	Source / Inference	Comment
Available Time	☐ More than sufficient time given the context	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Stress & Stressors	☐ Enhanced alertness / no negative effects	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Complexity	☐ Failures have single vs. multiple effects	☐ Source ☐ Inferred	
	☐ Causal connections apparent	☐ Source ☐ Inferred	
	☐ Dependencies well defined	☐ Source ☐ Inferred	
	☐ Few or no concurrent tasks	☐ Source ☐ Inferred	
	☐ Action straightforward with little to memorize and with no burden	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Experience & Training	☐ Frequently performed / well-practiced task	☐ Source ☐ Inferred	
	☐ Well qualified / trained for task	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Procedures & Reference Documents	☐ Guidance particularly relevant and correctly directed the correct action or response	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Ergonomics & HMI	☐ Unique features of HMI were particularly useful to this situation	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Fitness for Duty / Fatigue	☐ Optimal health / fitness was key to the success	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Work Processes	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	

PSF	Positive Contributory Factor	Source / Inference	Comment
Planning / Scheduling	☐ Correct work package development important to the success	☐ Source ☐ Inferred	
	☐ Work planning / staff scheduling important to the success	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Supervision / Management	☐ Clear performance standards	☐ Source ☐ Inferred	
	☐ Supervision properly involved in task	☐ Source ☐ Inferred	
	☐ Supervision alerted operators to key issue that they had missed	☐ Source ☐ Inferred	
	☐ Pre-task briefing focused on failure scenario that actually occurred / discussed response plans that were directly applicable	☐ Source ☐ Inferred	
	☐ Pre-task briefing alerted operators to potential problems in a way that made them alert to the situation that developed	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Conduct of Work	☐ Quick identification of key information was important to success	☐ Source ☐ Inferred	
	☐ Error found by 2nd checker, 2nd crew, or 2nd unit	☐ Source ☐ Inferred	
	☐ Important information easily differentiated	☐ Source ☐ Inferred	
	☐ Determining appropriate procedure to use in unique situation was important to success	☐ Source ☐ Inferred	
	☐ Complex system interactions identified and resolved	☐ Source ☐ Inferred	
	☐ Remembered omitted step	☐ Source ☐ Inferred	
	☐ Difficult or potentially confusing situation well understood	☐ Source ☐ Inferred	
	☐ Safety implications identified and understood in a way that was important to success	☐ Source ☐ Inferred	
	☐ Acceptance criteria understood and properly applied to resolve difficult situation	☐ Source ☐ Inferred	
	☐ Proper post-modification testing identified and ensured resolution of significant problem	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Problem Identification & Resolution (PIR) / Corrective Action Plan (CAP)	☐ Good trending of problems was important in correct diagnosis / response plan revision	☐ Source ☐ Inferred	
	☐ Adaptation of industry notices / practices was key to correct diagnosis / response plan verification	☐ Source ☐ Inferred	
	☐ Good corrective action plan avoided serious problems	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Communication	☐ Communications practice was key to avoiding severe difficulties	☐ Source ☐ Inferred	

PSF	Positive Contributory Factor	Source / Inference	Comment
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Environment	☐ Environment particularly important to success	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Team Dynamics / Characteristics	☐ Extraordinary teamwork and / or sharing of work assignments was important to success	☐ Source ☐ Inferred	
	☐ Exceptional coordination / communications clarified problems during event	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	

Section 4: Negative Contributory Factors / PSF Details

Indicate any negative factors that contributed to the subevent. Check all that apply; if no details apply for a PSF category, check None. Indicate whether the detail is selected based on evidence directly from the source or if it is coder inference. Leave a detailed comment, with reference to the source document. This information is used to determine the Performance Shaping Factor (PSF) level in Section 5. This table continues over the next three pages.

PSF	Negative Contributory Factor	Source / Inference	Comment
Available Time	☐ Limited time to focus on tasks	☐ Source ☐ Inferred	
	☐ Time pressure to complete task	☐ Source ☐ Inferred	
	☐ Inappropriate balance between available and required time	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Stress & Stressors	☐ High stress	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Complexity	☐ High number of alarms	☐ Source ☐ Inferred	
	☐ Ambiguous or misleading information present	☐ Source ☐ Inferred	
	☐ Information fails to point directly to the problem	☐ Source ☐ Inferred	
	☐ Difficulties in obtaining feedback	☐ Source ☐ Inferred	
	☐ General ambiguity of the event	☐ Source ☐ Inferred	
	☐ Extensive knowledge regarding the physical layout of the plant is required	☐ Source ☐ Inferred	
	☐ Coordination required between multiple people in multiple locations	☐ Source ☐ Inferred	
	☐ Scenario demands that the operator combine information from different parts of the process and information systems	☐ Source ☐ Inferred	
	☐ Worker distracted / interrupted (W2 198)	☐ Source ☐ Inferred	
	☐ Demands to track and memorize information	☐ Source ☐ Inferred	
	☐ Problems in differentiating important from less important information	☐ Source ☐ Inferred	
	☐ Simultaneous tasks with high attention demands	☐ Source ☐ Inferred	

PSF	Negative Contributory Factor	Source / Inference	Comment
	☐ Components failing have multiple versus single effects	☐ Source ☐ Inferred	
	☐ Weak causal connections exist	☐ Source ☐ Inferred	
	☐ Loss of plant functionality complicates recovery path	☐ Source ☐ Inferred	
	☐ System dependencies are not well defined	☐ Source ☐ Inferred	
	☐ Presence of multiple faults	☐ Source ☐ Inferred	
	☐ Simultaneous maintenance tasks required or planned	☐ Source ☐ Inferred	
	☐ Causes equipment to perform differently during the event	☐ Source ☐ Inferred	
	☐ Subevent contributes to confusion in understanding the event	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Experience & Training	☐ Fitness for Duty (FFD) training missing / less than adequate (LTA) (F 124)	☐ Source ☐ Inferred	
	☐ Training LTA (T 100)	☐ Source ☐ Inferred	
	☐ Training process problem (T 101)	☐ Source ☐ Inferred	
	☐ Individual knowledge problem (T 102)	☐ Source ☐ Inferred	
	☐ Simulator training LTA (T4 103)	☐ Source ☐ Inferred	
	☐ Work practice or craft skill LTA (W2 188)	☐ Source ☐ Inferred	
	☐ Not familiar with job performance standards	☐ Source ☐ Inferred	
	☐ Not familiar / well practiced with task	☐ Source ☐ Inferred	
	☐ Not familiar with tools	☐ Source ☐ Inferred	
	☐ Not qualified for assigned task	☐ Source ☐ Inferred	
	☐ Training incorrect	☐ Source ☐ Inferred	
	☐ Situation outside the scope of training	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Procedures & Reference Documents	☐ No procedure / reference documents (P 110)	☐ Source ☐ Inferred	
	☐ Procedure / reference document technical content less than adequate (LTA) (P 111)	☐ Source ☐ Inferred	
	☐ Procedure / reference document contains human factors deficiencies (P 112)	☐ Source ☐ Inferred	
	☐ Procedure / reference document development and maintenance LTA (P 113)	☐ Source ☐ Inferred	
	☐ Procedures do not cover situation	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Ergonomics & HMI	☐ Alarms / annunciators less than adequate (LTA) (H1)	☐ Source ☐ Inferred	
	☐ Controls / input devices LTA (H2)	☐ Source ☐ Inferred	
	☐ Displays LTA (H3)	☐ Source ☐ Inferred	
	☐ Panel or workstation layout LTA (H4)	☐ Source ☐ Inferred	
	☐ Equipment LTA (H5)	☐ Source ☐ Inferred	
	☐ Tools and materials LTA (H6)	☐ Source ☐ Inferred	
	☐ Labels LTA (H7)	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	

PSF	Negative Contributory Factor	Source / Inference	Comment
Fitness for Duty / Fatigue	☐ Working continuously for considerable number of hours	☐ Source ☐ Inferred	
	☐ Working without rest day for considerable time	☐ Source ☐ Inferred	
	☐ Unfamiliar work cycle	☐ Source ☐ Inferred	
	☐ Frequent changes of shift	☐ Source ☐ Inferred	
	☐ Problem related to night work	☐ Source ☐ Inferred	
	☐ Circadian factors / individual differences (F 127)	☐ Source ☐ Inferred	
	☐ Impairment (F 129)	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Work Processes	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Planning / Scheduling	☐ Work planning does not control excessive continuous working hours (F 125)	☐ Source ☐ Inferred	
	☐ Inadequate staffing / task allocation (W1 181)	☐ Source ☐ Inferred	
	☐ Scheduling and planning less than adequate (LTA) (W1 180)	☐ Source ☐ Inferred	
	☐ Work package quality LTA (W1 182)	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Supervision / Management	☐ Administrative assurance of personnel ability and qualification to perform work less than adequate (LTA) (F 120-122)	☐ Source ☐ Inferred	
	☐ Inadequate supervision / command and control (O1 130)	☐ Source ☐ Inferred	
	☐ Management expectations or directions less than adequate (O1 131)	☐ Source ☐ Inferred	
	☐ Duties and tasks not clearly explained / work orders not clearly given	☐ Source ☐ Inferred	
	☐ Progress not adequately monitored	☐ Source ☐ Inferred	
	☐ Inadequate control of contractors	☐ Source ☐ Inferred	
	☐ Frequent task re-assignment	☐ Source ☐ Inferred	
	☐ Pre-job activities (e.g., pre-job briefing) LTA (W1 183)	☐ Source ☐ Inferred	
	☐ Safety aspects of task not emphasized	☐ Source ☐ Inferred	
	☐ Informally sanctioned by management	☐ Source ☐ Inferred	
	☐ Formally sanctioned workarounds cause problem	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Conduct of Work	☐ Self-check less than adequate (LTA) (W2 197)	☐ Source ☐ Inferred	
	☐ Improper tools or materials selected / provided / used	☐ Source ☐ Inferred	
	☐ Necessary tools / materials not provided or used	☐ Source ☐ Inferred	
	☐ Information present but not adequately used	☐ Source ☐ Inferred	
	☐ Failure to adequately coordinate multiple tasks / task partitioning / interruptions	☐ Source ☐ Inferred	

PSF	Negative Contributory Factor	Source / Inference	Comment
	☐ Fitness for Duty self-declaration LTA (F 123)	☐ Source ☐ Inferred	
	☐ Fitness for Duty non-compliance (F 128)	☐ Source ☐ Inferred	
	☐ Control room sign off on maintenance not performed	☐ Source ☐ Inferred	
	☐ Tag outs LTA (W1 184)	☐ Source ☐ Inferred	
	☐ Second independent checker not used or available	☐ Source ☐ Inferred	
	☐ Work untimely (e.g., too long, late) (W2 192)	☐ Source ☐ Inferred	
	☐ Housekeeping LTA (W2 194)	☐ Source ☐ Inferred	
	☐ Logkeeping or log review LTA (W2 195)	☐ Source ☐ Inferred	
	☐ Independent verification / plant tours LTA (W2 196)	☐ Source ☐ Inferred	
	☐ Procedural adherence LTA (W2 185)	☐ Source ☐ Inferred	
	☐ Failure to take action / meet requirements (W2 186)	☐ Source ☐ Inferred	
	☐ Action implementation LTA (W2 187)	☐ Source ☐ Inferred	
	☐ Recognition of adverse condition / questioning LTA (W2 189)	☐ Source ☐ Inferred	
	☐ Failure to stop work / non conservative decision making (W2 190)	☐ Source ☐ Inferred	
	☐ Non-conservative action (W2 193)	☐ Source ☐ Inferred	
	☐ Failure to apply knowledge	☐ Source ☐ Inferred	
	☐ Failure to access available sources of information	☐ Source ☐ Inferred	
	☐ Post-modification testing inadequate	☐ Source ☐ Inferred	
	☐ Post-maintenance testing inadequate	☐ Source ☐ Inferred	
	☐ Retest requirements not specified	☐ Source ☐ Inferred	
	☐ Retest delayed	☐ Source ☐ Inferred	
	☐ Test acceptance criteria inadequate	☐ Source ☐ Inferred	
	☐ Test results review inadequate	☐ Source ☐ Inferred	
	☐ Surveillance schedule not followed	☐ Source ☐ Inferred	
	☐ Situational surveillance not performed	☐ Source ☐ Inferred	
	☐ Required surveillance / test not scheduled	☐ Source ☐ Inferred	
	☐ Incorrect parts / consumables installed / used	☐ Source ☐ Inferred	
	☐ Failure to exclude foreign material	☐ Source ☐ Inferred	
	☐ Incorrect restoration of plant following maintenance / isolation / testing	☐ Source ☐ Inferred	
	☐ Independent decision to perform work around or circumvention	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Problem Identification & Resolution (PIR) / Corrective Action Plan (CAP)	☐ Problem not completely or accurately identified (R1 140)	☐ Source ☐ Inferred	
	☐ Problem not properly classified or prioritized (R1 141)	☐ Source ☐ Inferred	
	☐ Operating experience review less than adequate (LTA) (R1 142)	☐ Source ☐ Inferred	
	☐ Failures to respond to industry notices or follow industry practices	☐ Source ☐ Inferred	

PSF	Negative Contributory Factor	Source / Inference	Comment
	☐ Tracking / trending LTA (R1 143)	☐ Source ☐ Inferred	
	☐ Root cause development LTA (R2 145)	☐ Source ☐ Inferred	
	☐ Evaluation LTA (R2 146)	☐ Source ☐ Inferred	
	☐ Corrective action LTA (R3 147)	☐ Source ☐ Inferred	
	☐ Action not yet started or untimely (R3 148)	☐ Source ☐ Inferred	
	☐ No action planned (R3 149)	☐ Source ☐ Inferred	
	☐ CAP Programmatic deficiency (R4 150)	☐ Source ☐ Inferred	
	☐ Willingness to raise concerns LTA (R5 151)	☐ Source ☐ Inferred	
	☐ Preventing and detecting retaliation LTA (R5 152)	☐ Source ☐ Inferred	
	☐ Failure to resolve known problems in a prompt fashion	☐ Source ☐ Inferred	
	☐ Failure to maintain equipment in accordance with licensing basis	☐ Source ☐ Inferred	
	☐ Audit / self-assessment / effectiveness review LTA (R1 144)	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Communication	☐ No communication / information not communicated (C 160)	☐ Source ☐ Inferred	
	☐ Misunderstood or misinterpreted information (C 51)	☐ Source ☐ Inferred	
	☐ Communication not timely (C 52)	☐ Source ☐ Inferred	
	☐ Communication content less than adequate (LTA) (C 53)	☐ Source ☐ Inferred	
	☐ Communication equipment LTA (C 162)	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Environment	☐ Temperature / humidity less than adequate (LTA) (H10 71)	☐ Source ☐ Inferred	
	☐ Lighting LTA (H10 72)	☐ Source ☐ Inferred	
	☐ Noise (H10 73)	☐ Source ☐ Inferred	
	☐ Radiation (H10 74)	☐ Source ☐ Inferred	
	☐ Work area layout or accessibility LTA (H10 75)	☐ Source ☐ Inferred	
	☐ Postings / signs LTA (H10 76)	☐ Source ☐ Inferred	
	☐ Task design / work environment LTA (F 126)	☐ Source ☐ Inferred	
	☐ Fire / smoke	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	
Team Dynamics / Characteristics	☐ Supervisor too involved in tasks, inadequate oversight	☐ Source ☐ Inferred	
	☐ Crew interaction style not appropriate to the situation	☐ Source ☐ Inferred	
	☐ Team interactions less than adequate (W2 191)	☐ Source ☐ Inferred	
	☐ Other: ___	☐ Source ☐ Inferred	
	☐ None / Not Applicable / Indeterminate	☐ Source ☐ Inferred	

Section 5: Performance Shaping Factors

Assign PSF ratings for the subevent. This section summarizes and assigns a PSF level (Insufficient Information, Good, Nominal, Poor) to the detailed performance shaping factor information indicated in Sections 3 and 4. Leave a detailed comment, with reference to the appropriate details sections.

PSF	PSF Level	Comment
Available Time	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Stress & Stressors	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Complexity	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Experience & Training	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Procedures & Reference Documents	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Ergonomics& HMI	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Fitness for Duty / Fatigue	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Work Processes	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Planning / Scheduling	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Supervision / Management	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Conduct of Work	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Problem Identification & Resolution (PIR) / Corrective Action Plan (CAP)	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Communication	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Environment	☐Insufficient Information ☐Good ☐Nominal ☐Poor	
Team Dynamics / Characteristics	☐Insufficient Information ☐Good ☐Nominal ☐Poor	

Section 6: Human Cognition

Part A: Human Information Processing

Indicate whether the error or success occurred in detection, interpretation, planning, action, a combination (check all that apply), or could not be determined from the source information.

Step		Comment
Detection: Detection or recognition of a stimulus (e.g., a problem, alarm, etc.)	☐ Correct detection ☐ Correct detection based on incorrect information ☐ Incorrect detection ☐ Not Applicable / Insufficient Information	

Step		Comment
Interpretation: Interpretation of the stimulus (e.g., understanding the meaning of the stimulus)	☐ Correct interpretation ☐ Correct interpretation based on incorrect detection ☐ Incorrect interpretation ☐ Not Applicable / Insufficient Information	
Planning: Planning a response to the stimulus	☐ Correct planning ☐ Correct plan based on incorrect interpretation / detection ☐ Incorrect plan ☐ Not Applicable / Insufficient Information	
Action: Executing the planned response	☐ Correct action ☐ Correct action based on incorrect plan / interpretation / detection ☐ Incorrect action ☐ Not Applicable / Insufficient Information	
Indeterminate	☐ Indeterminate	

Part B: Cognitive Level

Indicate whether the human activity involved in this subevent was skill-based, rule-based, knowledge-based, or could not be determined from the source information.

	Cognitive Level		Comment
☐	**Skill-Based:** Routine, highly-practiced task, carried out in a largely automatic fashion, with occasional conscious checks on progress.	☐Correct ☐Incorrect	
☐	**Rule-Based:** Task requires application of memorized or written rules (e.g., if, then), with conscious thinking to verify if the resulting solution is appropriate.	☐Correct ☐Incorrect	
☐	**Knowledge-Based:** Conscious, effortful thought and/or problem solving, often for a novel task or situation.	☐Correct ☐Incorrect	
☐	**Indeterminate**		

Section 7: Error Type ☐ Check to Exclude

Code for XHE only. Indicate the appropriate error type for any human errors (XHEs). Leave a detailed comment, with reference to the source document. This list continues on the next page.

Part A: Commission / Omission *(Select one.)*

	Error Type	Comment
☐	**Error of Commission:** An incorrect, unintentional, or unplanned action is an error of commission.	
☐	**Error of Omission:** Failure to perform an action is an error of omission.	
☐	**Indeterminate**	

Part B: Slip / Lapse / Mistake / Circumvention / Sabotage *(Select all that apply.)*

	Error Type	Comment
☐	**Slip or lapse:** A slip or lapse is an unconscious unintended action or failure to act, resulting from an attention failure or a memory failure in a routine activity. In spite of a good understanding of the system (process, procedure, specific context) and the intention to perform the task correctly, an unconscious unintended action or a failure to act occurs or a wrong reflex or inappropriate instinctive action takes place. If it is not possible to assign one of the subcategories below to indicate the type of slip or miss, then this code is assigned.	
☐	Response implementation error	
☐	Unconscious wrong action or failure to act, wrong reflex, wrong instinctive action	
☐	Wrong action or lack of action due to omission of intentional check, insufficient degree of attention, unawareness	
☐	Strong habit intrusion, unwanted reversion to earlier plan	
☐	Continuation of habitual sequence of actions	
☐	Failure to act because focal attention is elsewhere, failure to attend to need for change in action sequence	
☐	Omission of intentional check after task interruption	
☐	Interference error between two simultaneous tasks	
☐	Confusion error (wrong component, wrong unit), spatial disorientation (wrong direction), check on wrong object	
☐	Omission of steps or unnecessary repeating of steps in (unconscious) action sequence	
☐	Task sequence reversal error	
☐	If appropriate, check the most applicable characterization of the slip: ☐ too early ☐ too late ☐ too fast ☐ too slow ☐ too hard ☐ too soft ☐ too long ☐ too short ☐ undercorrect ☐ overcorrect ☐ misread	
☐	**Mistake:** A mistake is an intended action resulting in an undesired outcome in a problem solving activity: a person made a wrong action because he did not understand the system, the procedure, the specific context, the prescribed task, etc. Use this category if you cannot distinguish among the mistake examples listed below.	
☐	Misdiagnosis, misinterpretation, situation assessment error	
☐	Wrong mental model, wrong hypothesis	
☐	Failure to detect situation, information overload (indications not noticed, acted upon)	
☐	Use of wrong procedure	
☐	Misunderstood instructions / information	
☐	Lack of specific knowledge	
☐	Tunnel vision (focus on limited number of indications, lack of big picture)	
☐	Over-reliance on favorite indications	
☐	Not believing indications / information (lack of confidence)	
☐	Mindset / preconceived idea / confirmation bias / overconfidence (failure to change opinion, discarding contradictory evidence)	
☐	Over-reliance on expert knowledge	
☐	**Circumvention:** In spite of a good understanding of the system (process, procedure, specific context) an intentional breaking of known rules, prescriptions, etc., occurred without malevolent intention. Use this field if it is clear that a circumvention applies but unclear which of the options below apply.	
☐	Administrative control circumvented or intentionally not performed	
☐	Required procedures, drawings, or other references not used	
☐	Intentional shortcuts in prescribed task sequence	

	Error Type	Comment
☐	Unauthorized material substitution	
☐	Situations that require compromises between system safety and other objectives (production, personal or personnel safety, etc.)	
☐	Intentional disregard of safety prescriptions / concerns	
☐	**Sabotage:** An intentional breaking of known rules, prescriptions, etc., occurred with malevolent intention.	
☐	**Indeterminate**	

Section 8: Subevent Comments

Provide any additional remarks necessary to complete or supplement the worksheet analysis for this subevent.

APPENDIX C U.S. NPP FUNCTIONS, SYSTEMS AND COMPONENTS

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C.1 Major Plant Functions

C.1.1 Cornerstones and Cross-Cutting Areas

To measure plant performance, the NRC oversight program focuses on seven specific “cornerstones” which support the safety of plant operations in three key strategic performance areas:

- Reactor safety–avoiding accidents and reducing the consequences of accidents if they occur;
- Radiation safety–for both plant workers and the public during routine operations; and
- Safeguard-protection of the plant against sabotage or other security threats.

The seven cornerstones of plant safety are:

1. **Initiating Events**: This cornerstone focuses on operations and events at a nuclear plant that could lead to a possible accident, if plant safety systems did not intervene. These events could include equipment failures leading to a plant shutdown, shutdowns with unexpected complications, or large changes in the plant's power output.
2. **Mitigating Systems**: This cornerstone measures the function of safety systems designed to prevent an accident or reduce the consequences of a possible accident. The equipment is checked by periodic testing and through actual performance.
3. **Barrier Integrity**: There are three important barriers between the highly radioactive materials in fuel within the reactor and the public and the environment outside the plant. These barriers are the sealed rods containing the fuel pellets, the heavy steel reactor vessel and associated piping, and the reinforced concrete containment building surrounding the reactor. The integrity of the fuel rods, the vessel, and the piping is continuously checked for leakage, while the ability of the containment to prevent leakage is measured on a regular basis.
4. **Emergency Preparedness**: Each nuclear plant is required to have comprehensive emergency plans to respond to a possible accident. This cornerstone measures the effectiveness of the plant staff in carrying out its emergency plans. Such emergency plans are tested every two years during emergency exercises involving the plant staff and local, state, and, in some cases, federal agencies.
5. **Occupational Radiation Safety**: NRC regulations set a limit on radiation doses received by plant workers, and this cornerstone monitors the effectiveness of the plant's program to control and minimize those doses.
6. **Public Radiation Safety**: This cornerstone measures the procedures and systems designed to minimize radioactive releases from a nuclear plant during normal operations and to keep those releases within federal limits.
7. **Physical Protection**: Nuclear plants are required to have well-trained security personnel and a variety of protective systems to guard vital plant equipment, as well as programs to assure that employees are constantly fit for duty through drug and alcohol testing. This cornerstone measures the effectiveness of the security and fitness-for-duty programs.

In addition to the cornerstones, the reactor oversight program features three cross-cutting areas, so named because they potentially affect each of the cornerstones. The three-cross cutting areas and respective cross-cutting area components are (see NRC Inspection Manual Chapter 0305 for update):

1. **Human Performance**

A. *Decision-Making*: Licensee decisions demonstrate that nuclear safety is an overriding priority. Specifically (as applicable):

i. The licensee makes safety-significant or risk-significant decisions using a systematic process, especially when faced with uncertain or unexpected plant conditions, to ensure safety is maintained. This includes formally defining the authority and roles for decisions affecting nuclear safety, communicating these roles to applicable personnel, and implementing these roles and authorities as designed and obtaining interdisciplinary input and reviews on safety-significant or risk-significant decisions.

ii. The licensee uses conservative assumptions in decision making and adopts a requirement to demonstrate that the proposed action is safe in order to proceed rather than a requirement to demonstrate that it is unsafe in order to disapprove the action. The licensee conducts effectiveness reviews of safety-significant decisions to verify the validity of the underlying assumptions, identify possible unintended consequences, and determine how to improve future decisions.

iii. The licensee communicates decisions and the basis for decisions to personnel who have a need to know the information in order to perform work safely, in a timely manner.

B. *Resources*: The licensee ensures that personnel, equipment, procedures, and other resources are available and adequate to assure nuclear safety. Specifically, those necessary for:

i. Maintaining long term plant safety by maintenance of design margins, minimization of long-standing equipment issues, minimizing preventative maintenance deferrals, and ensuring maintenance and engineering backlogs which are low enough to support safety.

ii. Training of personnel and sufficient qualified personnel to maintain work hours within working hours guidelines.

iii. Complete, accurate and up-to-date design documentation, procedures, and work packages, and correct labeling of components.

iv. Adequate and available facilities and equipment, including physical improvements, simulator fidelity and emergency facilities and equipment.

C. *Work Control*: The licensee plans and coordinates work activities, consistent with nuclear safety. Specifically (as applicable):

i. The licensee appropriately plans work activities by incorporating:

   a. risk insights
   b. job site conditions, including environmental conditions which may impact human performance; plant structures, systems, and components; human-system interface; or radiological safety
   c. the need for planned contingencies, compensatory actions, and abort criteria

ii. The licensee appropriately coordinates work activities by incorporating actions to address:

   a. the impact of changes to the work scope or activity on the plant and human performance.
   b. the impact of the work on different job activities, and the need for work groups to maintain interfaces with offsite organizations, and communicate, coordinate, and cooperate with each other during activities in which interdepartmental coordination is necessary to assure plant and human performance.

c. the need to keep personnel apprised of work status, the operational impact of work activities, and plant conditions that may affect work activities.
d. the licensee plans work activities to support long-term equipment reliability by limiting temporary modifications, operator work-arounds, safety systems unavailability, and reliance on manual actions. Maintenance scheduling is more preventive than reactive.

D. *Work Practices*: Personnel work practices support human performance. Specifically (as applicable):
i. The licensee communicates human error prevention techniques, such as holding pre-job briefings, self and peer checking, and proper documentation of activities. These techniques are used commensurate with the risk of the assigned task, such that work activities are performed safely. Personnel are fit for duty. In addition, personnel do not proceed in the face of uncertainty or unexpected circumstances.
ii. The licensee defines and effectively communicates expectations regarding procedural compliance and personnel follow procedures.
iii. The licensee ensures supervisory and management oversight of work activities, including contractors, such that nuclear safety is supported.

2. **Problem Identification and Resolution**

A. *Corrective Action Program*: The licensee ensures that issues potentially impacting nuclear safety are promptly identified, fully evaluated, and that actions are taken to address safety issues in a timely manner, commensurate with their significance. Specifically (as applicable):
i. The licensee implements a corrective action program with a low threshold for identifying issues. The licensee identifies such issues completely, accurately, and in a timely manner commensurate with their safety significance.
ii. The licensee periodically trends and assesses information from the CAP and other assessments in the aggregate to identify programmatic and common cause problems. The licensee communicates the results of the trending to applicable personnel.
iii. The licensee thoroughly evaluates problems such that the resolutions address causes and extent of conditions, as necessary. This includes properly classifying, prioritizing, and evaluating for operability and reportability conditions adverse to quality. This also includes, for significant problems, conducting effectiveness reviews of corrective actions to ensure that the problems are resolved.
iv. The licensee takes appropriate corrective actions to address safety issues and adverse trends in a timely manner, commensurate with their safety significance and complexity.
v. If an alternative process (i.e., a process for raising concerns that is an alternate to the licensee’s corrective action program or line management) for raising safety concerns exists, then it results in appropriate and timely resolutions of identified problems.

B. *Operating Experience*: The licensee uses operating experience (OE) information, including vendor recommendations and internally generated lessons learned, to support plant safety. Specifically (as applicable):
i. The licensee systematically collects, evaluates, and communicates to affected internal stakeholders in a timely manner relevant internal and external OE.
ii. The licensee implements and institutionalizes OE through changes to station processes, procedures, equipment, and training programs.

C. *Self and Independent Assessments*: The licensee conducts self- and independent assessments of their activities and practices, as appropriate, to assess performance and identify areas for improvement. Specifically (as applicable):
   i. The licensee conducts self-assessments at an appropriate frequency; such assessments are of sufficient depth, are comprehensive, are appropriately objective, and are self-critical. The licensee periodically assesses the effectiveness of oversight groups and programs such as CAP, and policies.
   ii. The licensee tracks and trends safety indicators which provide an accurate representation of performance.
   iii. The licensee coordinates and communicates results from assessments to affected personnel, and takes corrective actions to address issues commensurate with their significance.

3. **Safety Conscious Work Environment**

A. *Environment for Raising Concerns*: An environment exists in which employees feel free to raise concerns both to their management and/or the NRC without fear of retaliation and employees are encouraged to raise such concerns. Specifically (as applicable):
   i. Behaviors and interactions encourage free flow of information related to raising nuclear safety issues, differing professional opinions, and identifying issues in the CAP and through self assessments. Such behaviors include supervisors responding to employee safety concerns in an open, honest, and non-defensive manner and providing complete, accurate, and forthright information to oversight, audit, and regulatory organizations. Past behaviors, actions, or interactions that may reasonably discourage the raising of such issues are actively mitigated. As a result, personnel freely and openly communicate in a clear manner conditions or behaviors, such as fitness for duty issues, that may impact safety, and personnel raise nuclear safety issues without fear of retaliation.
   ii. If alternative processes (i.e., a process for raising concerns or resolving differing professional opinions that are alternates to the licensee's corrective action program or line management) for raising safety concerns or resolving differing professional opinions exists, then they are communicated, accessible, have an option to raise issues in confidence, and are independent, in the sense that the program does not report to line management (i.e., those who would in the normal course of activities be responsible for addressing the issue raised).

B. *Preventing, Detecting, and Mitigating Perceptions of Retaliation*: A policy for prohibiting harassment and retaliation for raising nuclear safety concerns exists and is consistently enforced in that:
   i. All personnel are effectively trained that harassment and retaliation for raising safety concerns is a violation of law and policy and will not be tolerated.
   ii. Claims of discrimination are investigated consistent with the content of the regulations regarding employee protection and any necessary corrective actions are taken in a timely manner, including actions to mitigate any potential chilling effect on others due to the personnel action under investigation.
   iii. The potential chilling effects of disciplinary actions and other potentially adverse personnel actions (e.g., reductions, outsourcing, and reorganizations) are considered and compensatory actions are taken when appropriate.

C.1.2 Plant Functions for use in HERA

HERA has used the above safety cornerstones and cross-cutting areas as the basis for completing the “Affected Function(s)” fields in Worksheet A and Worksheet B. The functions and descriptions to assist the analysts in making coding assignments are presented below.

Plant Function	Performance Indicator	Measurement or Indicator
Initiating events [A]	Unplanned reactor shutdowns, including equipment failures and other factors leading to a plant shutdown	Automatic or Manual
Initiating events [B]	Loss of normal reactor cooling system and other unexpected complications following shutdown	Event description
Initiating events [C]	Unplanned events that result in significant changes in reactor power	Event description and percent power change
Mitigating Systems/Safety Systems [A]	Emergency Core Cooling Systems	Not available Failure mode
Mitigating Systems/Safety Systems [B]	Emergency Electric Power Systems	Not available Failure mode
Barrier Integrity [A]	Fuel Cladding	Radioactivity in reactor cooling system
Barrier Integrity [B]	Reactor cooling system	Leak rate
Barrier Integrity [C]	Containment Integrity	Equipment, procedure, or personnel inadequate
Emergency Preparedness [A]	Emergency response organization	Drill or event performance
Emergency Preparedness [B]	Readiness of emergency response organization	Evaluation or inspection
Emergency Preparedness [C]	Availability of notification system for area residents	Event report, surveillance, inspection, or test results
Occupational Radiation Safety [A]	Compliance with regulations for controlling access to radiation areas in plant	Event report, surveillance, inspection, or test results
Occupational Radiation Safety [B]	Uncontrolled radiation exposures to workers greater than 10 percent of regulatory limit	Event report, surveillance, inspection, or test results
Public Radiation Safety [A]	Effluent releases requiring reporting under NRC regulations and license conditions	Event report or inspection report
Physical Protection [A]	Plant security issues	Not publicly available
Physical Protection [B]	Fitness for Duty (FFD) program effectiveness	Event report or inspection report
Human performance [A]	Decision-Making	Identifiable human errors and successes
Human performance [B]	Resources	Identifiable human errors and successes
Human performance [C]	Work Control	Identifiable human errors and successes
Human performance [D]	Work Practices	Identifiable human errors and successes

Plant Function	Performance Indicator	Measurement or Indicator
Problem identification and resolution [A]	Corrective Action Program	The products of utility's corrective action program, e.g., discrepancy reports, trends reports, and corrective action plans
Problem identification and resolution [B]	Operating Experience	Use of internal and external OE to support safety
Problem identification and resolution [C]	Self and Independent Assessments	Use of self- and independent assessments to assess performance and identify areas for improvement
Safety-conscious work environment [A]	Environment for Raising Concerns	Management attention to safety and workers' ability to raise safety issues
Safety-conscious work environment [B]	Preventing, Detecting, and Mitigating Perceptions of Retaliation	Prohibition of retaliation and harassment for raising safety concerns

C.2. System Codes as Used in SPAR

The following tables list the systems and associated system codes used in PRA, by plant type. This information is used to populate the “Affected System” fields in HERA Worksheet A and Worksheet B.

C.2.1 Boiling Water Reactor (BWR) Systems

BWR System Codes	BWR System Descriptions
ACP	Plant ac power system
ADS	Automatic depressurization system
ARF	Air return fan system
CCW	Component cooling water
CDS	Condensate system
CGC	Containment combustible gas control
CHR	Containment heat removal
CHW	Chilled water system
CIS	Containment isolation system
CLS	Consequence limiting control system
CMS	Condensate makeup system
CPS	Containment penetration system
CRD	Control rod drive system
CSC	Closed cycle cooling system
CSS	Containment spray mode of residual heat removal
CTS	Condensate transfer system
DCP	dc power system
DGN	Diesel generator system
DGX	Diesel cross-tie system
DWS	Drywell (wetwell) spray mode of residual heat removal system
EHV	Emergency heating, ventilation, and air conditioning
ESF	Engineered safety feature actuation system
ESW	Emergency/essential service water system

BWR System Codes	BWR System Descriptions
FHS	Fuel handling system
FWS	Firewater system
GSW	General service water
HCI	High pressure coolant injection system
HCS	High pressure core spray system
HSW	High pressure service water system
IAS	Instrument air system
IPS	Instrument ac power system
ISO	Isolation condenser system
LCI	Low pressure coolant injection system
LCS	Low pressure core spray system
LPR	Low pressure coolant recirculation
MCW	Main circulating water system
MFW	Main feedwater system
MSS	Main steam system
NHV	Normal heating, ventilation, and air conditioning
NSS	Nuclear steam supply shutoff system
NSW	Normal service water
OEP	Offsite electrical power system
PCS	Power conversion system
PPR	Primary pressure relief system safety relief valves)
PSW	Plant service water system
RBC	Reactor building cooling water system
RCI	Reactor core isolation cooling system
RGW	Radioactive gaseous waste system
RHR	Residual heat removal system
RLW	Radioactive liquid waste system
RMT	Recirculation mode transfer system
RPS	Reactor protection system
RRS	Reactor recirculation system
RWC	Reactor water cleanup system
SDC	Shutdown cooling mode of residual heat removal
SFW	Standby feedwater system
SGT	Standby gas treatment system
SIS	Safety injection actuation system
SLC	Standby liquid control system
SPC	Suppression pool cooling mode of residual heat removal
SPM	Suppression pool makeup system
SSW	Standby service water system
SXT	Standby service water cross-tie system
TBC	Turbine building cooling water system
VSS	Vapor suppression system

C.2.2 Pressurized Water Reactor (PWR) Systems

PWR System Codes	PWR System Descriptions
ACP	Plant ac power system
AFW	Auxiliary feedwater system
ARF	Air return fan system

PWR System Codes	PWR System Descriptions
AVS	Annulus ventilation system
CAC	Containment atmosphere clean up
CCS	Containment cooling system
CFS	Core flood system
CDS	Condensate system
CCW	Containment emergency fan cooler system
CGC	Containment combustible gas control
CHP	Charging pump system
CWS	Chilled water system
CIS	Containment isolation system
CLS	Consequence limiting control system
CPC	Charging pump cooling system
CPS	Containment penetration system
CRD	Control rod drive system
CSC	Closed cycle cooling system
CSR	Containment spray recirculation system
CVC	Chemical and volume control system
DCP	dc power system
DGN	Diesel generator system
DGX	Diesel cross-tie system
EHV	Emergency heating, ventilation, and air conditioning
EPS	Emergency power system
ESF	Engineered safety features actuation system
ESW	Essential service water system
FHS	Fuel handling system
FWS	Firewater system
HPR	High pressure coolant recirculation system
HPI	High pressure injection
HWS	High pressure service water system
IAS	Instrument air system
ICS	Ice condenser system
IGS	Integrated control system
IPS	Instrument ac power system
ISR	Inside containment spray recirculation system
LMS	Let down purification and makeup system
LPI	Low pressure injection system
LPR	Low pressure recirculation system
LSW	Low pressure service water system
MCW	Main circulating water system
MFW	Main feedwater system
MSS	Main steam system
NHV	Normal heating, ventilation, and air conditioning
NSW	Normal service water
NWS	Nuclear service water system
OEP	Offsite electrical power system
OSR	Outside containment spray recirculation system
PCS	Power conversion system
PPR	Primary pressure relief system (pressure operated relief valves)
PSW	Plant service water system
PVS	Penetration room ventilation system

PWR System Codes	PWR System Descriptions
RBP	Reactor building penetration system
RCS	Reactor coolant system
RBS	Reactor building spray system
RCW	Reactor building cooling water system
RGW	Radioactive gaseous waste system
RHR	Residual heat removal system
RLW	Radioactive liquid waste system
RMT	Recirculation mode transfer system
RPS	Reactor protection system
RWC	Reactor water cleanup system
SIS	Safety injection actuation system
SLB	Steam line break control subsystem
SPR	Secondary pressure relief system
SSW	Standby service water system
SXT	Standby service water cross-tie system
TBC	Turbine building cooling water system

C.3 Component Codes as Used in SPAR

The following table lists the component codes as used in PRA. This information is used to populate the “Affected Component” fields in HERA Worksheet A and Worksheet B. Component codes are the same for BWRs and PWRs. These components are generic across systems; in order to identify the specific component affected, the component code must be linked to a system code. For each system code selected in Affected System(s), identify the affected component(s).

C.3.1 Component Codes

Component Codes	Component Descriptions
ACS	Actuation segment
ACT	Actuation train
ACU	Air cleaning unit
ACX	Air cooling heat exchanger
AHU	Air heating unit
AOV	Air operated valve
ASD	Physical position sensor/transmitter
ASF	Flow sensor/transmitter
ASL	Level sensor/transmitter
ASP	Pressure sensor/transmitter
ASR	Radiation sensor/transmitter
AST	Temperature sensor/transmitter
ASX	Flux sensor/transmitter
BAC	Electrical bus-ac
BAT	Battery
BCH	Battery charger
BDC	Electrical bus-dc
BTL	Compressed N2 bottle
CAL	Calculational unit

Component Codes	Component Descriptions
CBL	Electrical cable
CCF	Common cause failure event
CKD	Nonreturn damper
CKV	Check valve
CND	Signal conditioner
CRB	Circuit breaker
CRH	Control rod hydraulically driven
CRM	Control rod motor driven
DCT	Ducting
DGN	Diesel generator
EDP	Engine driven pump
EPV	Explosive valve
FAN	Motor driven fan
FCV	Flow control valve
FLT	Filter
FUS	Fuse
GTG	Gas turbine generator
HDV	Hydraulic valve
HRU	Hydrogen recombiner unit
HTR	Heater element
HTX	Heat exchanger
ICC	Instrumentation and control circuit
INV	Inverter
ISO	Electrical isolation device
LOD	Load/relay unit
LOG	Logic unit
LPS	Local power supply
MDC	Motor driven compressor
MDP	Motor driven pump
MGN	Motor generator unit
MOD	Motor operated damper
MOV	Motor operated valve
PHN	Phenomenological event
PND	Pneumatic/hydraulic damper
PSF	Pipe segment
PTF	Pipe train
REC	Rectifier
SMP	Sump
SOV	Solenoid operated valve
SRV	Safety/relief valve
STR	Strainer
TAC	ac electrical train
TCV	Testable check valve
TDC	dc electrical train
TDP	Turbine driven pump
TFM	Transformer
TNK	Tank
TSA	Traveling screen assembly
TSW	Transfer switch
TXX	Bistable trip unit

Component Codes	Component Descriptions
VCF	Miscellaneous aggregation of events
XDM	Manual damper
XHE	Operator action
XSW	Manual control switch
XVM	Manual valve

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APPENDIX D GLOSSARY

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Glossary

Note: Where applicable, definitions correspond to those found in ASME RA-Sb-2005, *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications.*

Action – As commonly used in HRA, that portion of human performance involving a response or activity (typically observable and often practiced or routine) that is carried out by the plant staff. In HERA, this aspect of human performance is documented as one step in the human information processing process (see *Detection*, *Interpretation*, and *Planning*). Human errors (XHEs) or successes (HSs) can stem from failure or success in response implementation.

Active – A subevent (XHE, HS, CI, XEQ, EQA, or PS) that has an immediate impact on a scenario or activity being performed, modeled, or analyzed. An active error can become a latent error if it is not detected and creates a situation that could affect a scenario later (e.g., failure to correctly restore a piece of equipment after maintenance that affects an operator's ability to respond to a later event). In HERA, an active subevent is any subevent that occurs during the event sequence being analyzed, regardless of whether it is pre- or post-initiator (see *Latent*, *Pre-Initiator*, and *Post-Initiator*).

Available Time – Performance shaping factor used in HERA. In HERA, available time considers the time available versus the time required to complete an action, including the impact of concurrent and competing activities.

Between-subjects design – an experimental manipulation for a control room simulator study whereby different crews participate in different parts or variants of a scenario.

Circumvention – The class of errors that occur when, in spite of a good understanding of the system (process, procedure, specific context), a person deliberately breaks known rules, prescriptions, etc., without malevolent intention, usually with the intention of maintaining safe or efficient operations.

Common Cause Failure (CCF) – A failure of two or more components during a single short period of time as a result of a single cause.

Communication – A performance shaping factor used in HERA that refers to the quality of verbal and written interaction between personnel working together at the NPP. This includes whether the content of communications are clear, complete, are verified and managed in such a way to ensure their receipt and comprehension, as well as whether one can be easily heard.

Complexity – A performance shaping factor used in HERA that refers to how difficult the task is to perform in the given context. Complexity considers how ambiguous or familiar the situation or task is, the number of separate inputs that are in mind simultaneously and possible causes, the mental effort and knowledge required of a task, the clarity of cause-and-effect relationships in task performance and system response, the number of actions required in a certain amount of time, and the physical effort or precision required. It also considers the environment in which the task is to be performed, any special sequencing or coordination that is required (e.g., if it involves multiple persons in different locations), the presence and number of parallel tasks or other distractions, and the presence and quality of indications. The more complex a task is, the greater the chance for error.

Contextual Information (CI) – represents contextual information about the human action or inaction. It is any human action or inaction that does not meet the classification criteria for an XHE or HS. Specifically, CI represents human activity or information that:

- Is associated with design errors or improper guidance; OR
- Takes place outside the NSSS and BOP systems; OR
- Is an engineering function including onsite engineering; OR
- Represents background or contextual information about the human activity in response to the situation; OR
- Encompasses conversations and notifications.

Also, contextual information may include any information that affects the quality of the human action or interaction with the plant or its systems and components, or helps to clarify motivations, intentions, or decisions of the personnel involved in the event. Common examples of information that should be considered CI include notifications or communication with the NRC, such as relevant generic letters or requests for information, industry notices that are relevant to the event in question, changes in or descriptions of management practices or policies, and descriptions of commonly held beliefs or biases that provide explanation for crew actions.

Conduct of Work – A subcategory of the Work Processes PSF. This includes all contributing factors to a subevent that involve performance of work activities, at both the individual and group level. This includes such factors as procedural adherence, whether work is done in a timely manner, appropriate or inappropriate use of knowledge and available information, recognition of adverse conditions, ability to coordinate multiple tasks, and proper use of tools and materials.

Cross-Cutting Area – Fundamental performance attributes that extend across all of the Reactor Oversight Process cornerstones of safety. These areas are human performance, problem identification and resolution, and safety conscious work environment. See U.S. NRC Inspection Manual Chapter (IMC) 0305 for definition update.

Cross-Cutting Area Component – A component of safety culture that is directly related to one of the cross-cutting areas. The cross-cutting area components in alphabetical order are: Corrective Action Program; Decision-Making; Environment for Raising Concerns; Operating Experience; Preventing, Detecting, and Mitigating Perceptions of Retaliation; Resources; Self and Independent Assessments; Work Control; and Work Practices. See U.S. NRC Inspection Manual Chapter (IMC) 0305 for definition update.

Contributory Plant Conditions – Any plant conditions that contribute to a human error (XHE) or human success (HS), and / or influence the decisions or actions of personnel, including system or equipment malfunctions or failures, power outages, equipment actuations, instrumentation problems, refueling outages, and transients.

Dependency – Dependency exists between two actions when an error on one action increases the probability that an error will occur on a subsequent action. HERA recognizes that it is possible for dependency to exist between two successes or between a success and a failure; however, current methods of calculating the effect of dependency on human error probability (HEP) cannot account for any dependency other than between human errors. As a result, dependency in HERA is considered between human errors (XHEs) only.

Dependent variable – that which is measured in a control room simulator study. The dependent variable may be a single or series of measures related to human performance in the scenario. The dependent variable is typically measured in response to the experimental manipulations of the independent variable. A normative model is assumed in which the independent variable causes an effect that may be measured in the dependent variable.

Detection – The human information processing step associated with seeking and monitoring, in which the human realizes or becomes aware that task relevant information is present. Detection is influenced by two fundamental factors: the characteristics of the environment and a person's knowledge and expectations (see *Interpretation*, *Planning*, and *Action*). Human errors (XHEs) or successes (HSs) can stem from failure or success in detection.

Dynamic initiator – A sudden scenario change in a control room simulator study. The dynamic initiator serves to change the conditions under which the control room is working. Often this change is instigated by the study investigator in order to observe crew performance.

Dynamic progression – A performance shaping factor that changes and evolves across the progression of a scenario in a control room simulator study. To capture change in the performance shaping factor, a dynamic progression should be assessed at multiple points throughout the duration of the simulator run.

Environment – A performance shaping factor used in HERA that refers to external factors such as ambient noise, temperature, lighting, weather, etc., which can greatly influence the quality and ability of personnel to carry out their prescribed tasks.

Equipment Actuation (EQA) – Plant subevent categorization used in HERA. Represents successful equipment actuation that is automatic, activating as designed, and not by human action that has or potentially has a positive effect on the event outcome.

Equipment Failure (XEQ) – Plant subevent categorization used in HERA. Represents an equipment (EQ) failure or malfunction that contributes or potentially contributes to the fault (X).

Ergonomics and Human-Machine Interface (HMI) – A performance shaping factor used in HERA. This is a broad category that encompasses all aspects of how persons interact with the plant systems, equipment, data or information interfaces, instrumentation, and other aspects of their environment. Included in this PSF are the availability and clarity of instrumentation, the quality and quantity of information available from instrumentation, the layout of displays and controls, the ergonomics of the control room or work location, the accessability and operability of the equipment to be manipulated (e.g., to manually open a valve requires an operator to climb over pipes and use a tool from an awkward position), the extent to which special physical fitness requirements, tools or equipment are needed to perform a task. The adequacy or inadequacy of computer interfaces or software is also included in this PSF.

Error of Commission – A human failure event resulting from an overt action, that, when taken, leads to a change in plant or system configuration with the consequence of a degraded plant or system state. Examples include terminating running safety-injection pumps, closing valves, and blocking automatic initiation signals.

Error of Omission – A human failure event resulting from a failure to take a required action, that leads to an unchanged or inappropriately changed plant or system configuration with the consequence of a degraded plant or system state. Examples include failures to initiate standby liquid control system, start auxiliary feedwater equipment, and failure to isolate a faulted steam generator.

Error type – A way of classifying human failure events related to the level of intent of the failure (error). In HERA, errors are categorized as either omission or commission, and as a slip or lapse, mistake, circumvention, or sabotage.

Event – Refers to an occurrence of one or more related operations and actions (called subevents in HERA; see *Subevents*) that, as applied here, are of interest from a human performance perspective. Often, this leads to a 'reportable occurrence' at a nuclear power plant. In HERA, an event includes the entire chronology of significant human actions and plant operational responses (i.e., subevents) contained in the information source.

Event timeline – A listing (Index of Subevents) and graphical representation of the significant human actions and plant operational responses (i.e., subevents) associated with an event. In HERA, this chronological information is especially useful for identifying fault or error precursors and for determining dependencies among human actions.

Experience & Training – A performance shaping factor used in HERA that includes consideration of experience of years of experience of the individual or crew, specificity of training to the work being performed, quality of training, and amount of time since training. This also includes how frequently an activity is performed (e.g., routinely vs. rarely) and an operator's familiarity or experience with a task or situation.

External Event (EE) – Subevent categorization used in HERA to represent subevents that occur external to the plant, such as transmission system events, severe weather, earthquakes, and lightning strikes.

Fitness for Duty/Fatigue – A performance shaping factor used in HERA that refers to whether or not the individual performing the task is physically and mentally fit to perform the task at that time. This includes such considerations as fatigue, illness, drug use (legal or illegal), physical and mental health, overconfidence, personal problems, time of day, and work schedule.

Human Action Category – Generalized categories of errors that are modeled in probabilistic risk assessments (PRAs) and some categories for events that may be studied for possible future use in risk assessments. For example, HERA analyzes human actions that precede an initiating event, while current PRAs do not include human actions in setting initiating event frequencies, but use actual industry plant trip experience data instead. Each XHE and HS analyzed is checked against the list of categories and placed in the one that best fits the situation.

Human Error Probability (HEP) – A measure of the likelihood that plant personnel will fail to perform the correct, required, or specified action or response in a given situation or by commission performs the wrong action.

Human Failure Event (HFE) – A basic event that is modeled in the logic models of a PRA (event and fault trees), and that represents a failure or unavailability of a component, system, or function that is caused by human inaction or inappropriate action. A human failure event reflects the PRA systems' modeling perspective. This is a specific term used in Human

Reliability Analysis (HRA) and is not to be confused with the HERA subevent category of Human Error (XHE).

Human reliability analysis (HRA) – A structured approach used to identify potential human failure events and to systematically estimate the probability of those events using data, models, or expert judgment. HERA provides information that may be used to inform various HRA methods.

Human Success (HS) – Human subevent categorization used in HERA. Represents a successful human action or inaction that has or potentially has a positive effect on the event outcome. A HS is a human action or inaction that:

- Occurs within the boundary of the NSSS and BOP systems; *AND*
- Potentially positively affects plant, system, equipment availability, operability, and consequences; *OR*
- Represents a recovery action; *OR*
- Represents a circumvention with positive impact.

Independent variable – The plant state or condition that is manipulated in a control room simulator study. An independent variable is the differentiating factor across study scenarios and variants. All other contributors are held constant, while a single variable is altered to determine its specific effect on human performance.

Initiating Event – Any event either internal or external to the plant that perturbs the steady state operation of the plant, if operating, thereby initiating an abnormal event such as transient or loss of coolant accident (LOCA) within the plant. Initiating events trigger sequences of events that challenge plant control and safety systems whose failure could potentially lead to plant damage. For example, a reactor trip or an actuation of an engineered safety feature would be an initiating event. In HERA, an initiating event is labeled as *Initiator (INIT)* in the Index of Subevents.

Interpretation – The active process by which individuals create an understanding of what is happening in a given situation, in real time, based on the current inputs from the monitoring and detection activities, and based on an individual's knowledge and experience. Human faults (XHEs) or successes (HSs) can stem from failure or success in interpretation.

Latent – A subevent (XHE, HS, CI, EQA, or XEQ) that does not have an immediate effect on system performance, but whose consequences can become important at a later time, particularly when they are triggered by a subsequent activity.

Knowledge-based level – The cognitive level that comes into play in novel situations for which rules are not available. Operators are required to use conscious analytical processing and stored knowledge to develop a solution to the problem at hand. Knowledge-based tasks require conscious, effortful thought or problem solving, and as such, processing when in this mode tends to be slow, sequential, laborious, and resource-limited. Errors at this level tend to be mistakes that arise from resource limitations, inadequate understanding of the problem, overconfidence, or incomplete or incorrect knowledge.

Mistake – The class of errors that occur when a person is following a plan diligently, but the plan is inadequate to achieve its goal. A mistake occurs when an intended action results in an undesired outcome. Mistakes can be rule-based, as when an inappropriate rule or procedure is selected for a situation or when a good rule is misapplied, or knowledge-based, as when the situation is not fully understood and no rules are available to aid operators in solving the problem.

Performance Shaping Factor (PSF) – A factor that influences human performance and the resulting human error probabilities as considered in a HRA. In HERA, there are eleven PSFs (rated as Insufficient Information, Good, Nominal, or Poor): Available Time, Stress & Stressors, Complexity, Experience & Training, Procedures and Reference Documents, Ergonomics & Human-Machine Interface (HMI), Fitness for Duty, Work Processes, Communication, Environment, and Team Dynamics / Characteristics.

Performance Shaping Factor Detail / Contributory Factor – Positive and negative contributing factors to human errors (XHEs) and successes (HSs), organized by the corresponding performance shaping factor (PSF). The PSF table (Section 5 of Worksheet B) serves as a summary of the information in the contributory factors / PSF details sections (Sections 3 and 4 of Worksheet B). The purpose of the PSF table (Section 5) is to rank the influence of a particular PSF on a human subevent based on the details identified in Sections 3 and 4. That ranking can then be used to apply a modification value to the calculation of the HEP.

Planning and Scheduling – Subcategory of the Work Processes PSF that includes those contributing factors to a subevent that involve planning work activities and scheduling. Work planning includes work package development and ensuring that personnel have enough resources (e.g., tools, materials, or funding) to perform work. Scheduling includes ensuring sufficient and appropriate personnel are available to perform work. It also includes ensuring that personnel are not scheduled to work too much overtime.

Plant State (PS) – Plant subevent categorization used in HERA that represents information about the plant state that is used to explain the equipment failure, actuation, or other noteworthy factors pertaining to plant health or transients.

Post-Initiator – Any subevent (XHE, HS, CI, EE, XEQ, or EQA) that occurs during response to an initiating event.

Pre-Initiator – Subevents (human errors, successes, contextual information, and equipment actuations or failures) that occurred prior to the initiation of an accident (e.g., during maintenance or the use of calibration procedures, etc.).

Probabilistic risk assessment (PRA) – A qualitative and quantitative assessment of risk associated with plant operation and maintenance that is measured in terms of frequency of occurrence of risk metrics such as core damage or radioactive material release and its effects on the health of the public (also referred to as a probabilistic safety assessment (PSA)).

Procedures and Reference Documents – A performance shaping factor used in HERA that refers to the availability, applicability, and quality of operating procedures, guidance or reference documents, or best practices for controlling work quality for the tasks under consideration. It can also refer to policies and rules or regulations that govern work at a plant. When assessing the influence of procedures and reference documents on a subevent, analysts should consider the degree to which the available procedures clearly and unambiguously address the situation at hand, completeness, accuracy, the degree to which procedures assist the crew in making correct diagnoses, the extent to which persons have to rely on memory, and how easy or difficult the procedure is to read, follow, or implement.

Problem Identification and Resolution (PIR) / Corrective Action Plan (CAP) – Subcategory of the Work Processes PSF that includes all contributing factors to a subevent that involve identifying and resolving problems at a plant. This includes factors such as classification of issues, root cause development, planning and implementation of corrective actions, review of operating experience, trending of problems, individuals' questioning attitudes and willingness to raise concerns, and preventing and detecting retaliation.

Recovery – A human action performed to regain equipment or system operability from a specific failure or human error to mitigate or reduce the consequences of the failure.

Rule-based level – The cognitive level at which operators tackle familiar problems via application of memorized or written rules (e.g., if, then), with conscious thinking to verify the correct rule to use and to verify if the resulting solution is appropriate. Errors made when in this mode tend to be mistakes due to application of the wrong rule or incorrect recall of procedures.

Sabotage – The class of errors that encompass an intentional breaking of known rules, prescriptions, etc., with malevolent intention.

Scenario – Generically, the term scenario refers to the progression of an event. It also has a specific meaning associated with simulator studies. In a simulator study, the term scenario refers to the series of tasks encompassed in a single control room simulator study. A scenario is treated equivalent to an event in HERA, and the scenario tasks are treated as subevents. A scenario commonly features one or more experimental manipulations to simulate off-normal conditions at the plant. The scenario begins with the initiation of the off-normal conditions and ends after a prescribed amount of time or after successful restoration of safe plant conditions.

Skill-based level – The cognitive level at which human performance is routine, highly-practiced, and carried out in a largely automatic fashion, with occasional conscious checks on progress. At this level, the operator is highly familiar with the environment or task. Errors made when in this mode tend to be slips or lapses.

Slip / Lapse – The category of errors that occur when a person intends to take the correct action, but either takes a wrong action (a slip) or fails to take the action they intended (a lapse). A slip or lapse is an unconscious unintended action or failure to act, resulting from an attention failure or a memory failure in a routine activity. In spite of a good understanding of the system (process, procedure, and specific context) and the intention to perform the task correctly, an unconscious unintended action or a failure to act occurs or a wrong reflex or inappropriate instinctive action takes place. Simple examples would include turning the wrong switch when the correct one is located next to it or inadvertently leaving out a step in a procedure when they fully intended to complete the step.

Static condition – A performance shaping factor that remains constant across a scenario in a control room simulator study. A static condition may be assessed at one point in time and held or assumed constant throughout the duration of a simulator run.

Stress and Stressors – A performance shaping factor used in HERA that is broadly defined to describe the mainly negative, though occasionally positive arousal that impacts human performance. A small amount of stress can be beneficial and enhance performance. More often, stress contributes to performance detriments. When evaluating the impact of stress as a PSF, analysts should consider workload, task complexity, time pressure, perceptions of pressure or threat, familiarity with the situation at hand, physical stressors such as those imposed by environmental conditions (e.g., high heat, noise, poor ventilation, poor visibility, or radiation). Clearly, stress is context-dependent; it is not independent of other PSFs. If other PSFs such as available time, complexity, training, or fitness for duty are poor, it is probable that stress is elevated. Analysts should consider the situation as a whole, including the other relevant PSFs, when assessing stress as a PSF.

Subevents – Individual operations and actions that contribute to an overall event. Each subevent is identified in the Index of Subevents in Worksheet A, and selected human subevents have a separate analysis in HERA Worksheet B.

Subevent codes – Symbols used to categorize the negative or positive effects of subevents. HERA employs the following codes: human failure (i.e., error) (XHE), successful human action (HS), equipment failure (XEQ), successful equipment actuation/operation (EQA), human contextual information (CI), plant state contextual information (PS), and external event (EE).

Supervision and Management – A subcategory of the Work Processes PSF that includes all contributing factors to a subevent that involve supervision of work and organizational or management issues. This includes such factors as command and control, quantity, quality, and appropriateness of supervision, whether work orders or instructions are given clearly, management emphasis on safety, weaknesses and strengths in organizational attitudes and administrative guidance, and organizational acceptance of workarounds.

Team Dynamics / Characteristics – A performance shaping factor used in HERA that refers to the crew interaction style and whether it is appropriate to the situation at hand. This PSF is specific to characterizing the crew as a whole and how the dynamics within or between teams influence performance and event response. Specifically, team dynamics and characteristics include such aspects as the degree to which independent actions are encouraged or discouraged, supervision style (e.g., democratic or authoritarian), presence of common biases or informal rules, such as how procedural steps are to be interpreted or which steps can be skipped, how well the crew ensures that everyone stays informed of activities or plant status, and the overall approach of the crew in responding to an event, such as aggressive or slow and methodical (Kolaczkowski, et al, 2005). It is important to note that HERA does not identify any one type of crew interaction style as “better” than others; the effect of crew characteristics is largely dependent on the situation under analysis and whether the crew dynamics were appropriate to that situation.

Variant – A secondary condition introduced to a scenario in simulator studies. For example, an off-normal plant scenario may feature masked (hidden or misleading indicators) or unmasked variants. Typically, some crews will take part in one variant condition of the scenario, while another portion of the crews will take part in the other variant.

Within-subjects design – An experimental manipulation for a control room simulator study whereby all crews participate in all scenarios.

Work Processes – A performance shaping factor used in HERA that refers to aspects of doing work, including inter-organizational, work planning, and management support and policies. In HERA, Work Processes consists of four subcategories of Planning and Scheduling, Supervision and Management, Conduct of Work, and Problem Identification and Resolution (PIR) / Corrective Action Plan (CAP).

Work Type – The classifications of work activity being performed by workers at the time a human error (XHE) or success (HS) occurs. In HERA, Work Type is also indicated with contextual information (CI), when applicable. HERA utilizes the Human Factors Information System (HFIS) work type categories and definitions.

XHE – Human subevent categorization used in HERA. Represents a human fault (see discussion in Section 2.3.3.1) that has or potentially has a negative effect on the event progression. An XHE is a human action or inaction that:

- Occurs within the boundary of the nuclear steam supply system (NSSS) and balance of plant (BOP) systems; *AND*
- Is unsafe; *OR*
- Negatively or potentially negatively affects plant, system, equipment availability, operability, and consequences; *OR*
- Represents a circumvention with negative impact.

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APPENDIX E CHANGES TO HERA STRUCTURE SINCE VOLUME 1

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E.1 Changes to HERA Structure Since Volume 1

Following the publication of HERA NUREG/CR-6903, Volume 1, some changes were made to the structure of the HERA worksheets in order to clarify and improve the information collected by HERA. The changes are summarized below, and the current versions of the worksheets are included as Appendices A and B.

E.1.1 Changes to Worksheet A

Section 1: Plant and Event Overview

- Items #7-9: The language of these items has been changed to "Affected Function/System/Component", eliminating the duplication of "Potential loss" and "Actual Loss" for simplicity. Now, analysts only identify the affected system(s), function(s), and component(s), whether a loss occurred or not. A list of major functions, systems, components is provided in Appendix C. In the database, based on the selection made in Plant Type, a drop-down list of applicable systems and components, with"Other" and "None" options as well, is provided. The functions, systems, and components identified here are linked to Worksheet B so analysts can indicate which human subevents affected the plant.
- Item #10: Simulator Study was added to classify data from simulator studies, including information on experiment, scenario, variant, and crew. A discussion of these fields is included in Chapter 3 of this report.

E.1.2 Changes to Worksheet B

Section 2: Plant Conditions

- Part B, Effects on Plant: This section allows analysts to pair the subevent with the specific effects on plant functions, systems, and components identified in Worksheet A.

Section 5: Performance Shaping Factors

- Detection, Interpretation, Planning, and Action was removed from this section and inserted into a new Section 6 (see discussion below).
- Under Work Processes, new "sub-PSFs" were added, including planning/scheduling, supervision/management, conduct of work, and problem identification and resolution, in order to be able to rank the influence of the sub-categories of the Work Processes PSF.

Section 6: Human Cognition

This new section was added in order to address the completeness of information regarding human cognition that is collected in HERA.

- Part A, Human Information Processing delineates the steps in the human decision making process (e.g., detection, interpretation, planning, and action). Because the terms XHE and HS are defined from a plant perspective (see discussion in 2.1.1 and 2.3.5, Section 6, below) this allows analysts to identify whether each step of human activity in the process was either correct, correct based upon a previous error, or incorrect, regardless of subevent status as a XHE or HS.
- Part B, Cognitive Level adds Rasmussen's Skill/Rule/Knowledge Based cognitive levels for consistency.