Human Reliability Analysis (HRA)
P-203

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United States
Nuclear Regulatory Commission

Idaho National Laboratory

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Human Error Spoiler:
No "G"

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Overview of Lessons

0. Overview (This Section)
1. Introduction to Human Reliability Analysis (HRA)
2. Human Error Basics
3. HRA Identification Phase
4. HRA Modeling Phase
5. HRA Quantification Phase
6. Expert Estimation
7. HRA Methods Overview
8. HRA Good Practices

Overview of Appendices

A. The Fallible Engineer
B. Medical Misadministration Example
C. THERP Table 20
D. THERP Exercises
E. SPAR-H Worksheets
F. SPAR-H Exercises

Course Materials

No Required Textbook

Supplemental CD

- Contains a number of significant NUREGs and other documents related to the course content (many not currently available online)
- Open the CD and click on “index.htm” for an index of files
- Please take with you and put on your bookshelf for reference

Recommended Readings in HRA

- James Reason, *Human Error*, Cambridge University Press, 1990.
- David I. Gertman & Harold S. Blackman, *Human Reliability & Safety Analysis Data Handbook*, Wiley Interscience, 1994.
- Barry Kirwan, *A Guide to Practical Human Reliability Assessment*, Taylor & Francis, 1994.
- James Reason, *Managing the Risks of Organizational Accidents*, Ashgate, 1997.
- James Reason & Alan Hobbs, *Managing Maintenance Error: A Practical Guide*, Ashgate, 2003.
- Oliver Sträter, *Cognition and Safety: An Integrated Approach to Systems Design and Assessment*, Ashgate, 2005.
- Sidney Dekker, *The Field Guide to Understanding Human Error*, Ashgate, 2006.
- Erik Hollnagel, David D. Woods, & Nancy Leveson (Eds.), *Resilience Engineering: Concepts and Precepts*, Ashgate, 2006.

LESSON 1

Introduction to Human Reliability Analysis (HRA)

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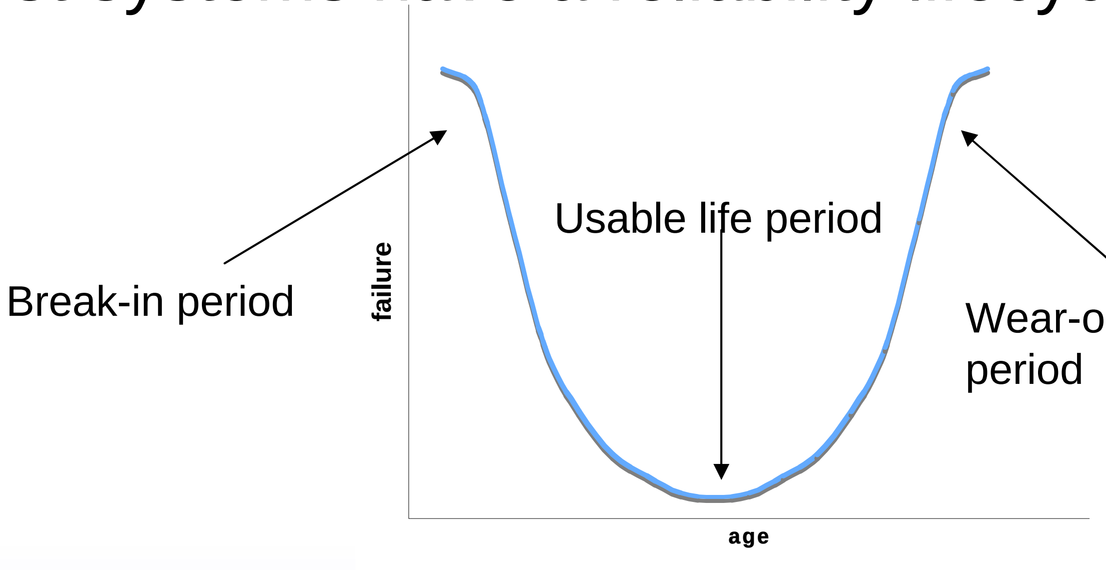
INL

Reliability Engineering

Reliability = Likelihood of Failure

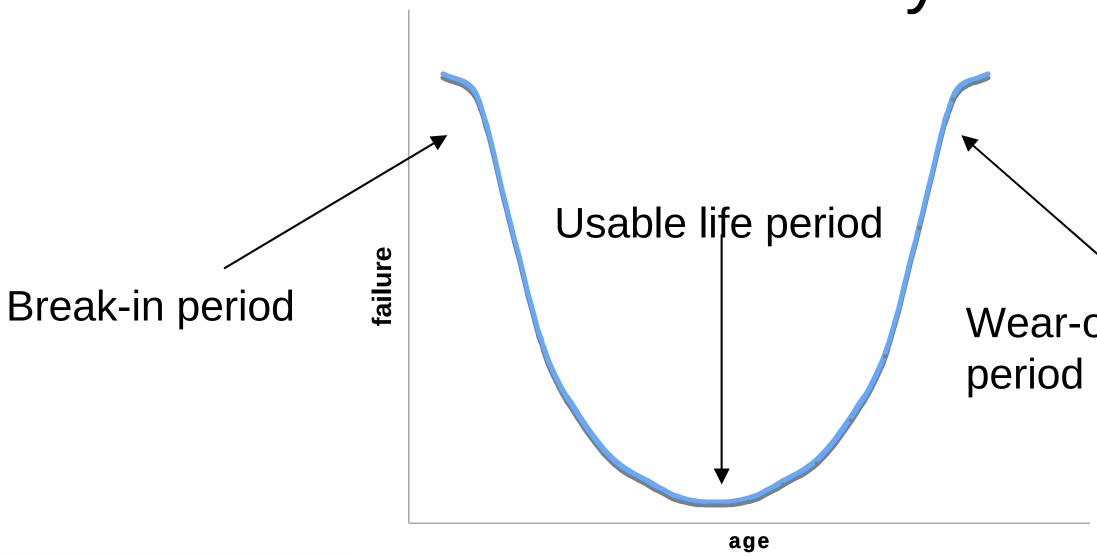
- A “high reliability” system is one that does not fail
- A “low reliability” system is one that does fail
- Most systems have a reliability lifecycle—a product life



Human Reliability Analysis?

How Does Human Reliability Relate?

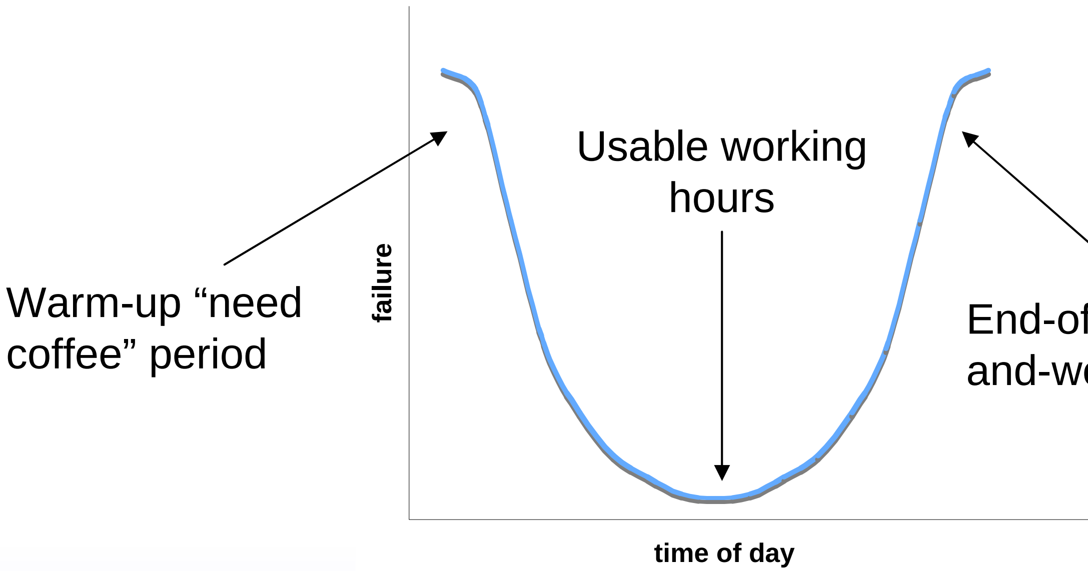
- Do we measure human reliability in terms of a break-in period, usable life period, and wear-out period?
- No! Humans are complex dynamic systems
  - – Machines don't have bad days—but humans do



A Day in the Life of A Human

Do Humans Have a Product Life?

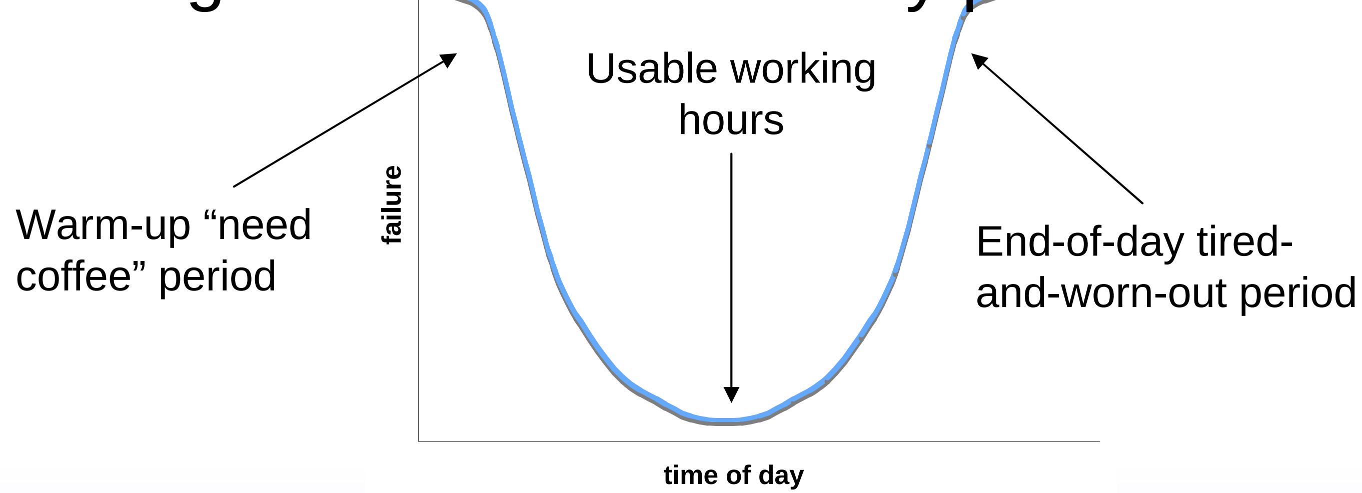
- We do have productive working years, but our reliability actually varies throughout the day
- Circadian rhythm—24-hour rest-wake cycle



Factors Affecting Human Reliability

What Can Cause Humans to Perform Worse?

- What might increase the warm-up period?
- What might decrease working performance during day?
- What might increase end-of-day period?



Definitions

Human Reliability Analysis (HRA) is:

- Study of what factors affect human performance
  - Broadly, as a research effort
  - Focused, as part of specific tasks that need to be reviewed in terms of safe operations
- Study of human contribution to overall risk when interacting with a system
  - Part of probabilistic risk assessment (PRA) that includes hardware and human reliability


R I S K

What is Risk?

Definition of Risk

- In the simplest of terms, risk is the likelihood of a hazard causing loss or damage

Risk is often framed in terms of the *Risk Triplet*:

- *What can go wrong?*
- *How likely is it?*
- *What are the consequences?*

What is Risk in Human Terms?

Definition of Risk

- Risk is the likelihood of a human error causing loss or damage

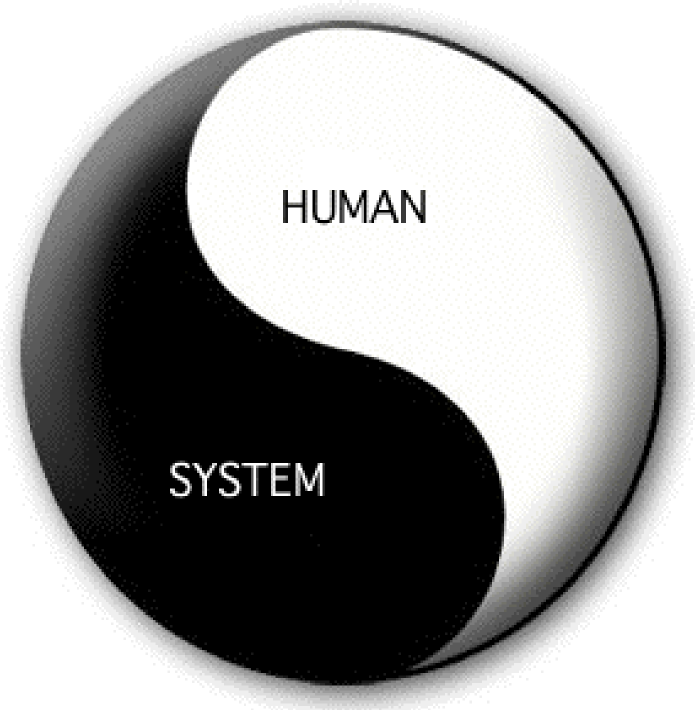
Definition of Human Error

- Unwanted actions (or inactions) that deviate from expected and accepted courses of action

Human risk can also be framed in the *Risk Triplet*:

- *What human actions can go wrong?*
- *How likely are these actions?*
- *What are the consequences of these actions?*

HRA in Risk Assessment: The BIG Picture



RISK

- Risk assessment looks at human-system activities and interactions and identifies the pathways by which the system mission might fail
- In a number of safety critical applications, people may actually be the predominant source of risk, not the system or hardware

Some Context

PRA *- Probabilistic Risk Assessment = Hardware and environmental contribution to risk*

↓

HRA *- Human Reliability Analysis = Human contribution to risk*

↑

HFE *- Human Factors Engineering = Study of human performance when using technology*

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Read and Discuss “The Fallible Engineer” (Appendix A)

Discussion Topics

- *What happened?*
- *Who was responsible?*
- *Where does human error occur?*
- *Who is to blame?*
- *What are the implications for reactors?*

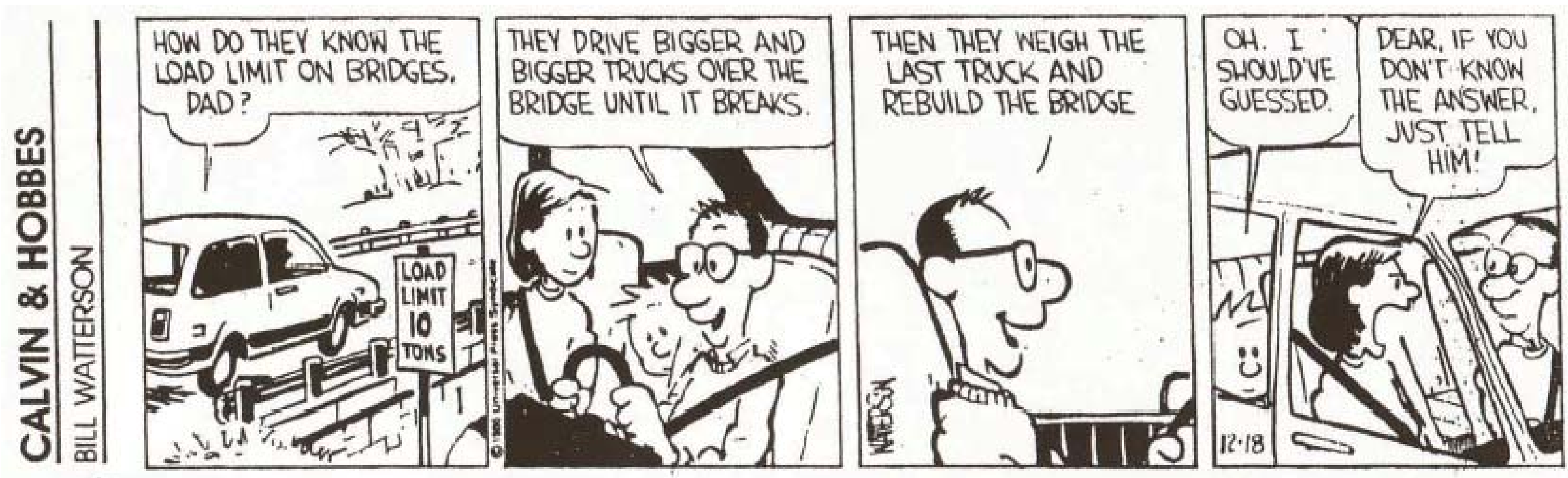
Risk is defined as the probability of an incident and its consequences

<u>Risk Assessment</u>

Qualitative - identify possible human and hardware failure conditions

Quantitative - calculate probabilities of those failure conditions

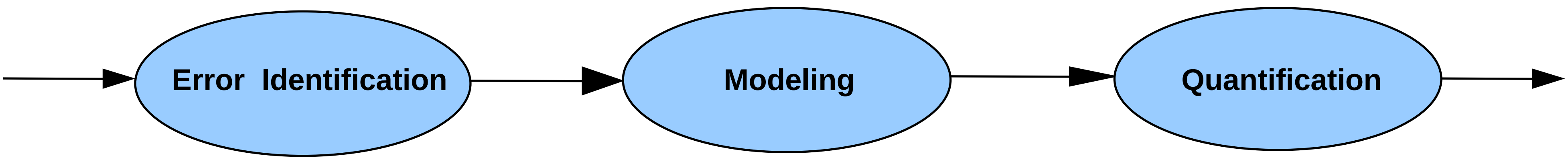
Assessing Risk in the Old Days



Three Basic Phases of HRA

HRA is a formal process to:

- Identify sources of human errors and error likely scenarios
- Model those human errors into an overall risk model
- Quantify Human Error Probabilities (HEPs)



Error Identification	Modeling	Quantification
task analysis	dynamic event trees	data availability
error taxonomies	fault trees	data bases
context	event trees	simulation
performance shaping factors	generic error models	empirical approaches
errors of commission		consensus expert judgment

Two Types of HRA

Retrospective HRA

- Review previous incidents and determine the root cause of the incident in terms of human error
- Review the likelihood of the incident occurrence given the context and ways to prevent recurrence
- Example: Regulator review of licensee event

Prospective HRA

- Identify possible sources of human error in a system that has not been implemented or for an incident that has not been encountered
- Example: Licensee submittals for regulatory approval

History of HRA

Alan Swain, 1972

History of HRA 1950 - 1970

1950s - 1st HRA, Sandia National Lab. - studied human error in aircraft weapons systems; Sandia continued HRAs within nuclear weapons manufacturing & handling

1962 - 1st human reliability data bank - AIR Data Store; 1st presentation of HRA to Human Factors Society

1964 - 1st HRA Symposium, Albuquerque

1967 - HRA technique accounts for dependencies between operators or tasks

1969 - USAF developed technique to model probability of error as a function of time, etc

History of HRA 1970 - 1990

1970s - Development of THERP for nuclear power; use of simulator data

1980s - THERP revised, ASEP produced; new simulation models; concern over safety & reliability of nuclear power industry (TMI); standardized HRA process; new HRA databases; new expert estimation techniques; increasing integration of HRAs into PRAs. Chernobyl typifies the role of human error in disaster. Recovery addressed

Modeling frameworks; Rasmussen: Skill-, Rule-, and Knowledge-based behavior; Reason: slips, lapses and mistakes

Time reliability correlation

History of HRA 1990 - present

1990s - Consideration of management and organizational factors heightened, SPAR-H HRA method released, development of additional cognitive-oriented models including ATHEANA, CREAM, CAHR, HEART, MERMOS, HRA calculator, the investigation of work process (WPAM). IEEE STD 1082 (1997), ORE studies.

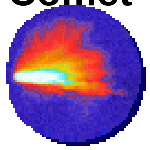
2000s - Compilation of HRA datasets for nuclear industry, aviation, and aeronautics. Application of ATHEANA. UK NARA effort. EPRI HRA Calculator, Application of HRA in support of NASA exploration. HRA Good Practices. Generalization of HRA results outside nuclear power industry. HRA benchmark. HERA database. Bayesian approaches explored.

HRA Methods Timeline

CD's First Released

1983

Return of Halley's Comet



1986

Hubble Telescope Launched

1990

Existence of Black Holes Proven

1994

Olympic Games Atlanta

1996

First Balloon Trip Around the World

1999

Today

2009

<u>THERP (1983)</u>
Pre-IE
Post-IE
Recovery
Dependency

<u>SHARP (1984)</u>
HRA Framework

<u>HCR (1984)</u>
First HCR

<u>SLIM-MAUD</u> (1984)

<u>ASEP (1987)</u>
Simplified THERP

<u>HEART</u> (1986)

<u>ORE (1989)</u>
Operator Reliability Experiments

<u>SHARP1 (1991)</u>
Revised Framework

<u>CBDTM (1992)</u>
Cause-Based Decision Trees

<u>ASP/SPAR</u> (1994)

<u>ATHEANA</u> (1996)

<u>CREAM</u> (1998)

<u>MERMOS</u> (1998)

<u>ATHEANA</u> (Rev.1 2000)

<u>CAHR</u> (1999)

<u>EPRI (2000)</u>
HRA Users Group

<u>SPAR-H</u> (2005)

<u>NARA</u> (2004)

<u>Halden Benchmarking</u> (2006-2010)

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Three Generations of HRA

- **Numerous distinctions have been posited**
- **The four classificatory Cs of generational HRA distinguish first and second generation HRA:**

Classification	1G	2G
Cognition	✘ No	✓ Yes
Context	✘ No	✓ Yes
Commission	✘ No	✓ Yes
Chronology	✘ Older	✓ Newer

- **Dynamic modeling approaches have been suggested as the third generation**

LESSON 2

From Human Error to HRA

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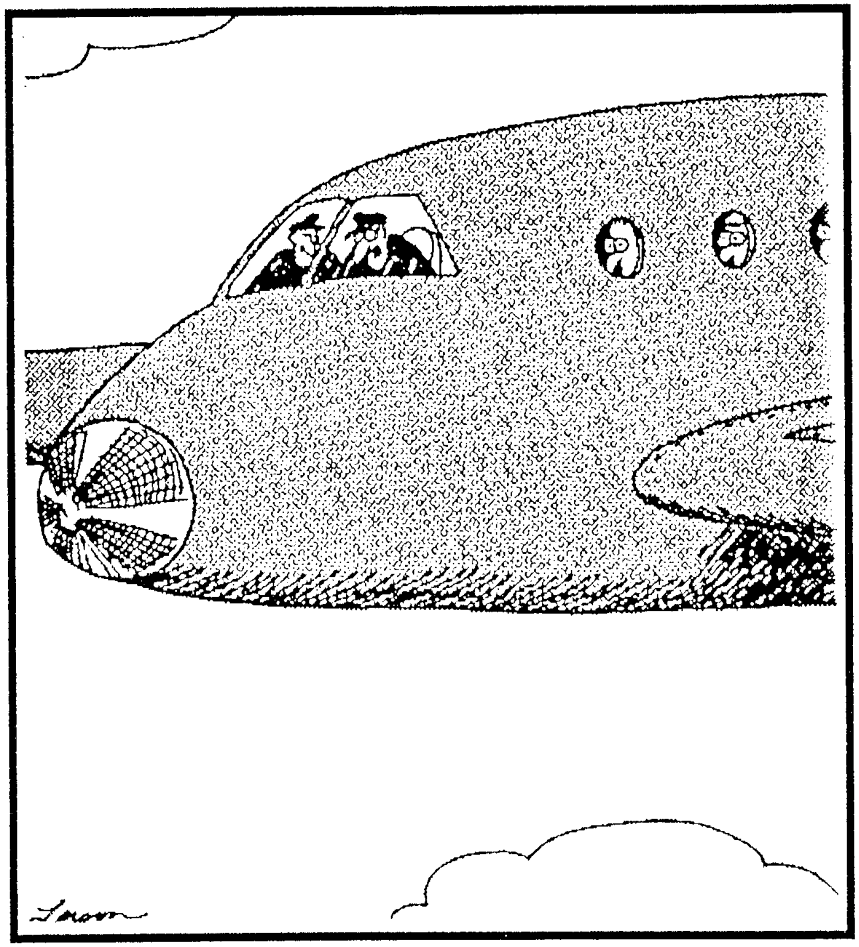
What do we mean by human error?



“The fuel light’s on, Frank! We’re all going to die!...We’re all going to die!..Wait, wait...Oh, my mistake - that’s the intercom light.”

What is Human Error?

- Unwanted actions or inactions that arise from problems in sequencing, timing, knowledge, interfaces, and/or procedures that result in deviations from expected standards or norms that places people, equipment, and systems at risk.

or

- A failure on the part of the human to perform a prescribed act (or performance of a prohibited act) within specified limits of accuracy, sequence or time, which could result in damage to equipment, or property, or disruption of schedules operations.

or

- An out of tolerance action, or deviation from the norm, where the limits of acceptable performance are defined by the system.

or

- Unplanned, unintentional, or intentional action or circumvention.

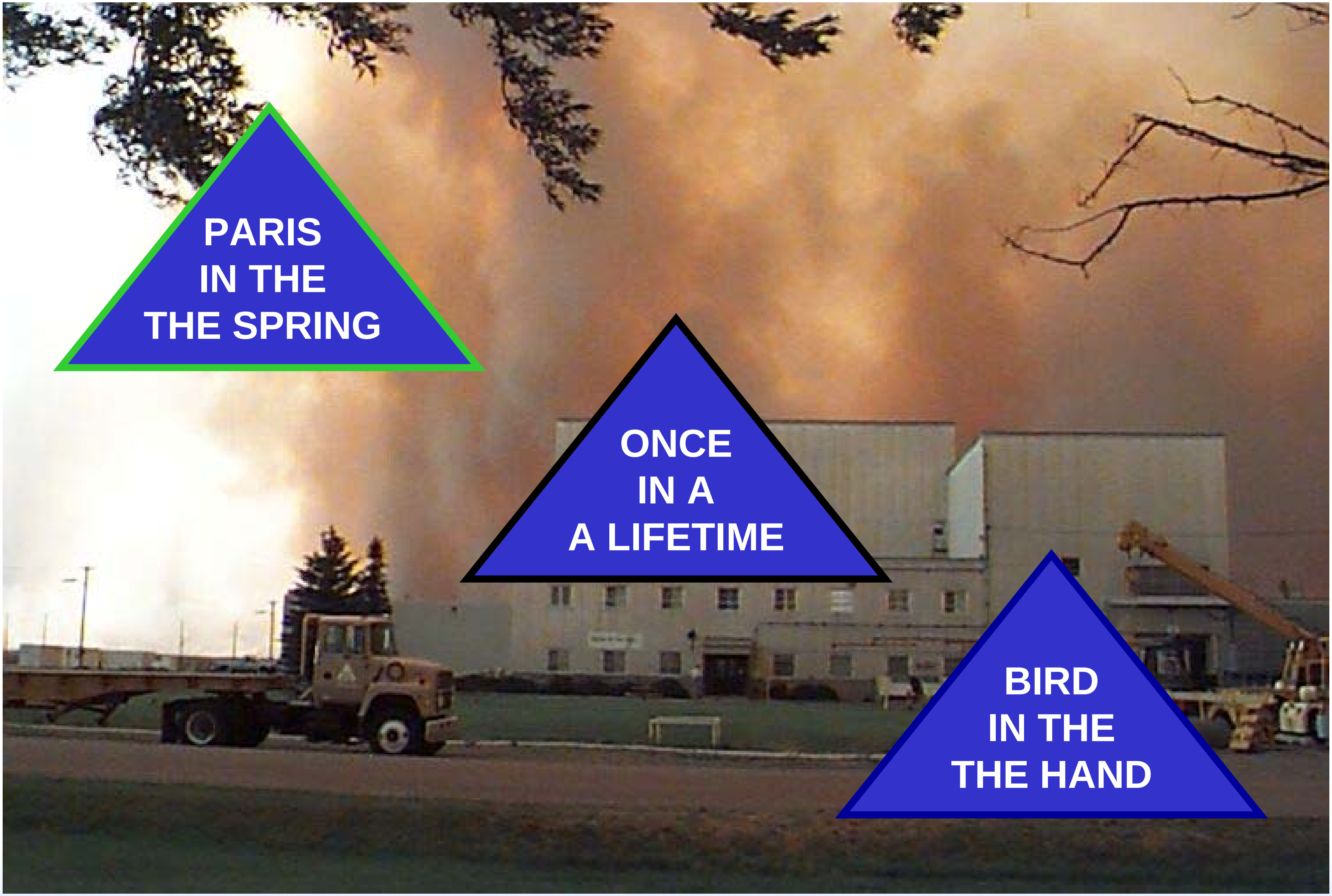
Simple Definition of Human Error

Human Error - Unwanted actions or inactions that result in deviations from expected standards or norms and that potentially place people, equipment, and systems at risk

Exercise: How many f's?

Finished Files are the Result of Years of Scientific Study Combined With the Experience of Many Years.

Classroom Exercise: Read the three phrases.


PARIS
IN THE
THE SPRING
ONCE
IN A
A LIFETIME
BIRD
IN THE
THE HAND

Aoccdrnig to a rscheearch at Cmabrigde Uinervtisy, it deosn't mttaer in waht oredr the ltteers in a wrod are, the olny iprmoetnt tihng is taht the frist and lsat ltteer be at the rghit pclae. The rset can be a toatl mses and you can sitll raed it wouthit porbelm. Tihs is bcuseae the huamn mnid deos not raed ervey lteter by istlef, but the wrod as a wlohe.

For a better explanation, see:
http://www.mrc-cbu.cam.ac.uk/~mattd/Cmabrigde/

Human Error is Everywhere

Even routine tasks like reading, writing, and speaking are extremely error prone

- The propensity to commit errors is further increased in complex tasks requiring extensive training, expertise, and procedural compliance

Humans are resilient

- Even though we commit errors frequently, most are inconsequent
  - A stumble in my speech does not prevent you from understanding what I am saying from the context of the rest of the sentence
- Many potentially consequential errors are spontaneously **recovered**
  - We self-check and correct errors
  - Safety systems or others “catch” the errors and help us correct them

Human Error is a Significant Contributor to Risk

➡	Accidents at Sea	90%
➡	Chemical Industry	80-90%
➡	Airline Industry	60-87%
➡	Commercial Nuclear Industry	65%

From: D.I. Gertman & H.S. Blackman, *Human Reliability & Safety Analysis Data Handbook*, Wiley-Interscience, 1994.

Human error has been shown to contribute from 50 to 70% of the risk at nuclear power plants

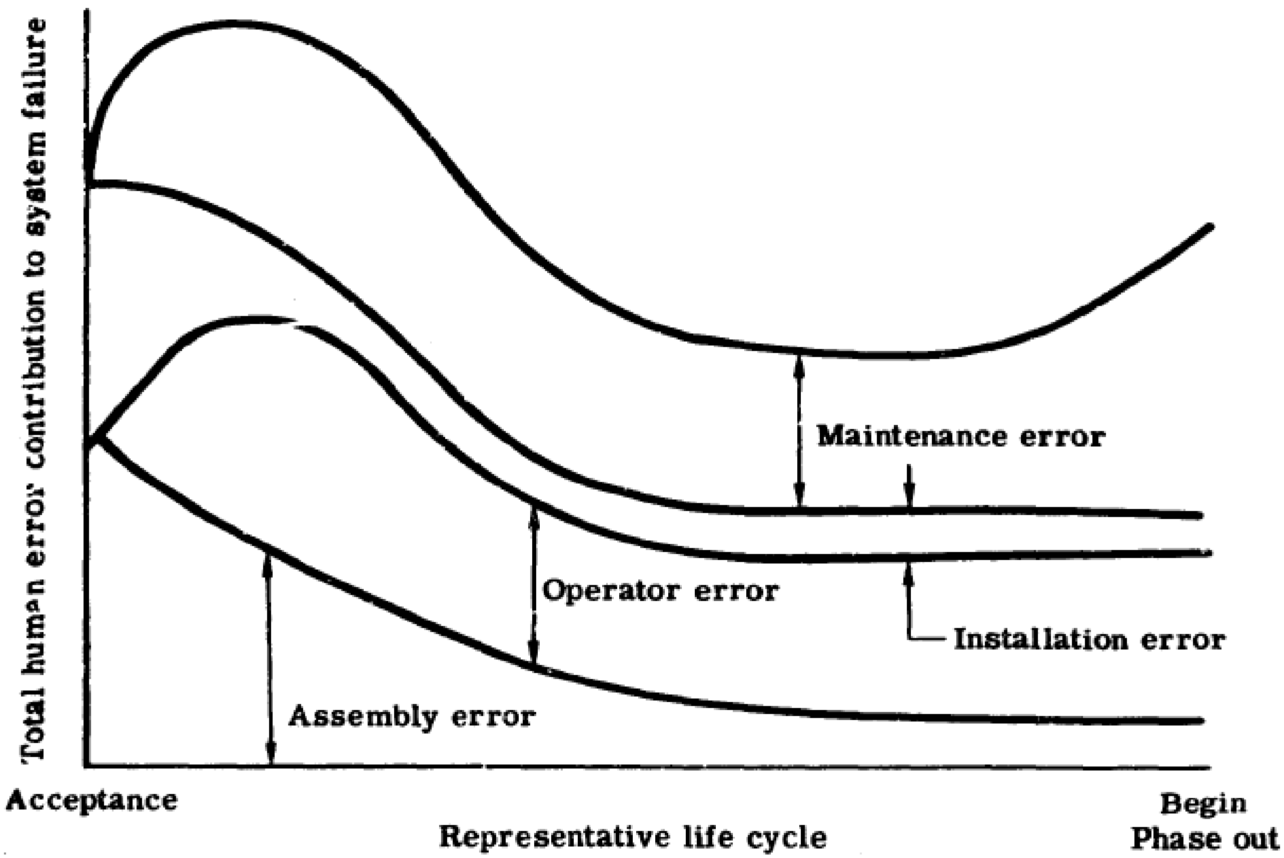
From: T.A. Trager, Jr., *Case Study Report on Loss of Safety System Function Events, AEOC/C504,* US NRC, 1985.

Importance of Human Error in Risk

From NUREG/CR-6753 (2002)

Power Plant	Event Date	LER Number	SPAR Analysis CCDP	Risk Factor Increase (CCDP/CDP)	Event Importance (CCDP-CDP)	Human Error Percent Contribution to Event Importance
Wolf Creek 1	1/30/96	482/96-001	5.2E-03	24,857	5.2E-03	100
Indian Point 2	8/31/99	AIT 50-246/99-08	3.5E-04	25	3.4E-04	100
McGuire 2	12/27/93	370/93-008	4.6E-03	2.4	2.7E-03	82
Haddam Neck	6/24/93	213/93-006 & -007 AIT 213/93-80	2.0E-04	4.3	1.5E-04	48

Different Errors Contribute to Failure



Proportional contribution of the different types of human error to overall failure (Rigby, 1967)

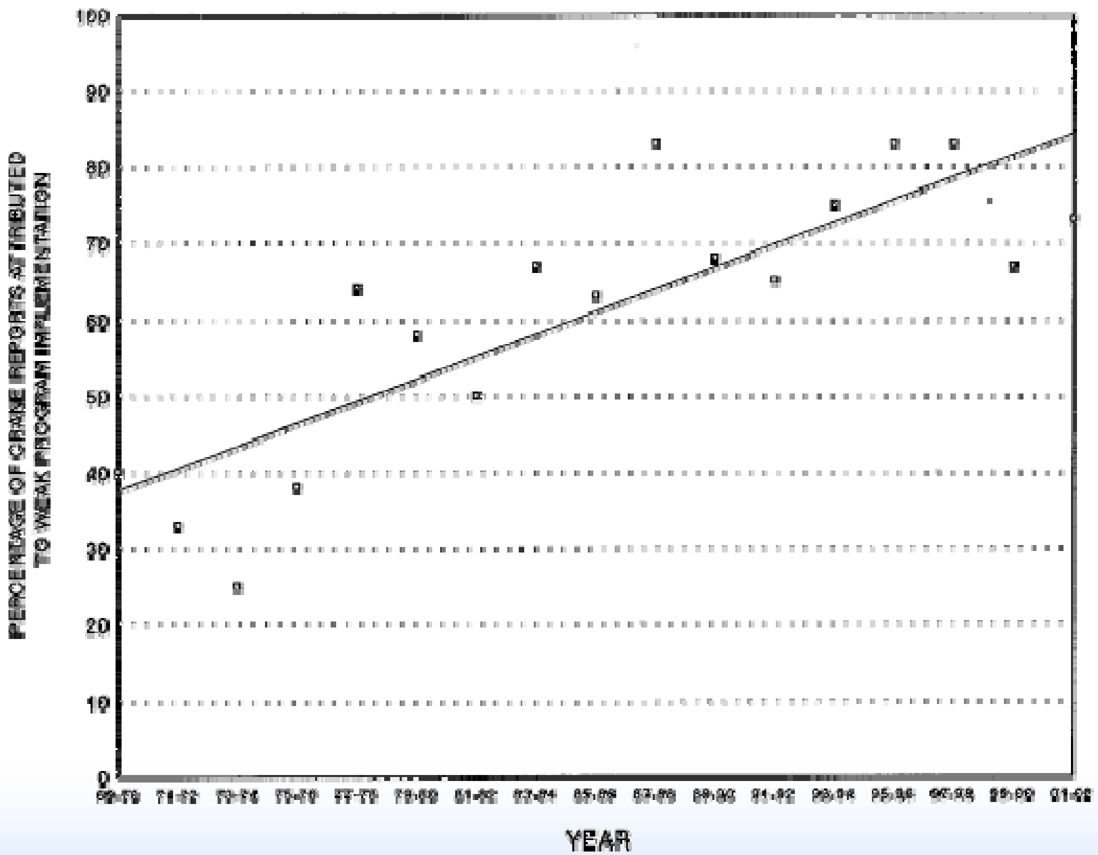
Types of Human Error Identified in Augmented Inspection Teams (AIT) Reports

Human Error Type	AIT (40 teams)
Procedures	65%
Training	40%
Supervision	43%
Human Engineering	40%
Communications	35%
Management & Organization	83%
Individual Issues	38%
Workload	10%
System Design	58%
Work Environment	8%

Errors Can Occur Across Plant Operations

NUREG-1774 chronicles crane operations from 1968 – 2002

- An average of 73% of incidents involved human performance
  - Is the human performance component increasing?



Human Errors in Crane Operations

Largest human contributors to crane events in NUREG-1774

- Not following procedures
- Failure to establish the required ventilation prior to load movements in certain areas
- Failure to perform crane surveillance tests prior to use
- Failure to move loads over established safe load path areas

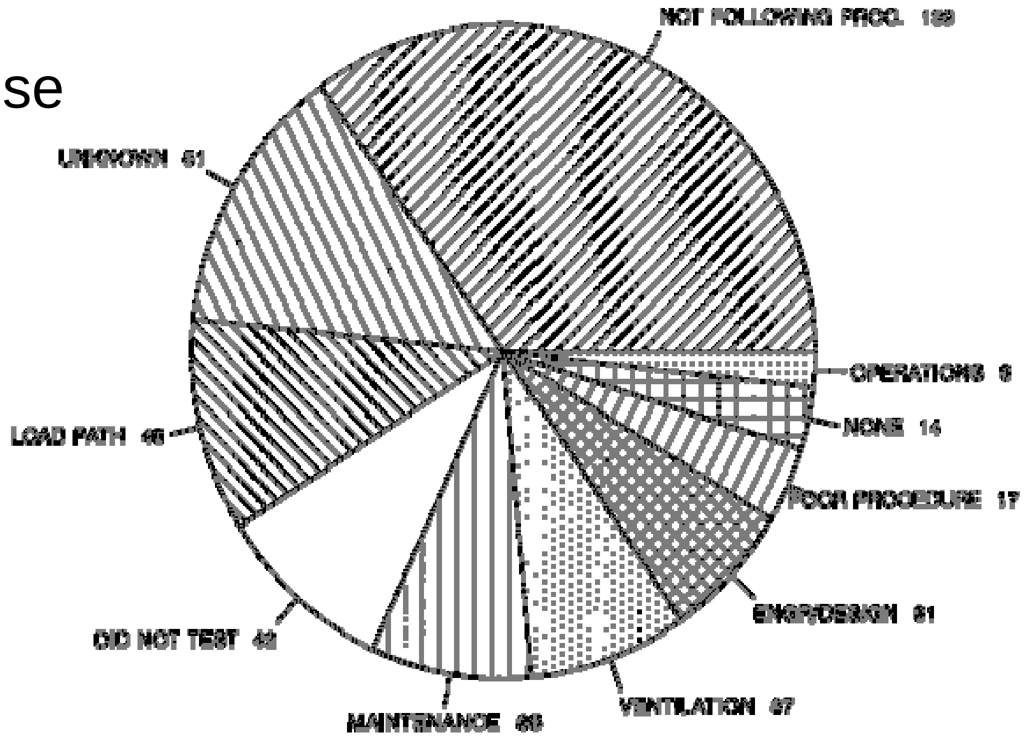
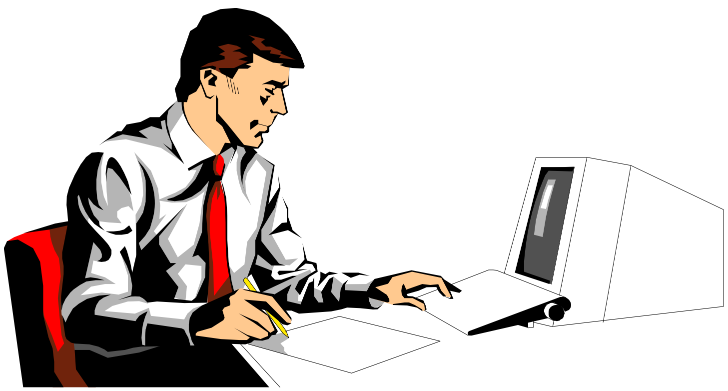


Figure 6: Principal reasons for crane events

Active Versus Latent Errors

Active Error

Active Errors are unsafe acts, failures of technological functions or human actions, which become the local triggering events that afterwards are identified as the immediate causes of an accident.



Latent Error

Latent Errors result in latent conditions in the system that may become contributing causes for an accident. They are present within the system as unnoticed conditions well before the onset of a recognizable accident sequence.

We do know that:

Active Errors + Latent Errors + Unique Situations

lead to **ACCIDENTS**!

Latent and Active Error Frequencies from 37 Operating Events (NUREG/CR-6753, 2002)

Category (followed by human performance influence)	Latent Errors	Active Errors
Operations		
Command and control issues including crew resource management,	4	14
Failure to follow safe practices	1	
Inadequate knowledge or training	12	2
Incorrect operator actions	3	7
Communications	3	2
Design and Design Change Work Process		
Design deficiencies	19	
Design change testing	5	
Inadequate engineering evaluation	8	
Ineffective indications for abnormal condition	1	
Configuration management	6	1

Latent and Active Error Frequencies (cont.)

Category (followed by human performance influence)	Latent Errors	Active Errors
Maintenance Work Process		
Poor work package preparation, QA and use	7	
Inadequate maintenance practices	17	
Inadequate technical knowledge	4	
Inadequate post-maintenance Testing	9	
Procedural Design and Development Process		
Inadequate procedures	18	1
Organizational Learning and Corrective Action Program		
Failure to respond to industry and internal notices	7	
Failure to follow industry operating practices	2	
Failure to identify by trending and problem reports	10	
Failure to validate vendor reports		

Latent and Active Error Frequencies (cont.)

Category (Followed by human performance influence)	Latent Errors	Active Errors
Work Prioritization		
Failure to correct known deficiencies	15	
Continue to operate during unstable conditions	1	2
Management Oversight		
Inadequate supervision	10	5
Inadequate knowledge of plant systems and plant requirements	2	1
Organizational structure	1	

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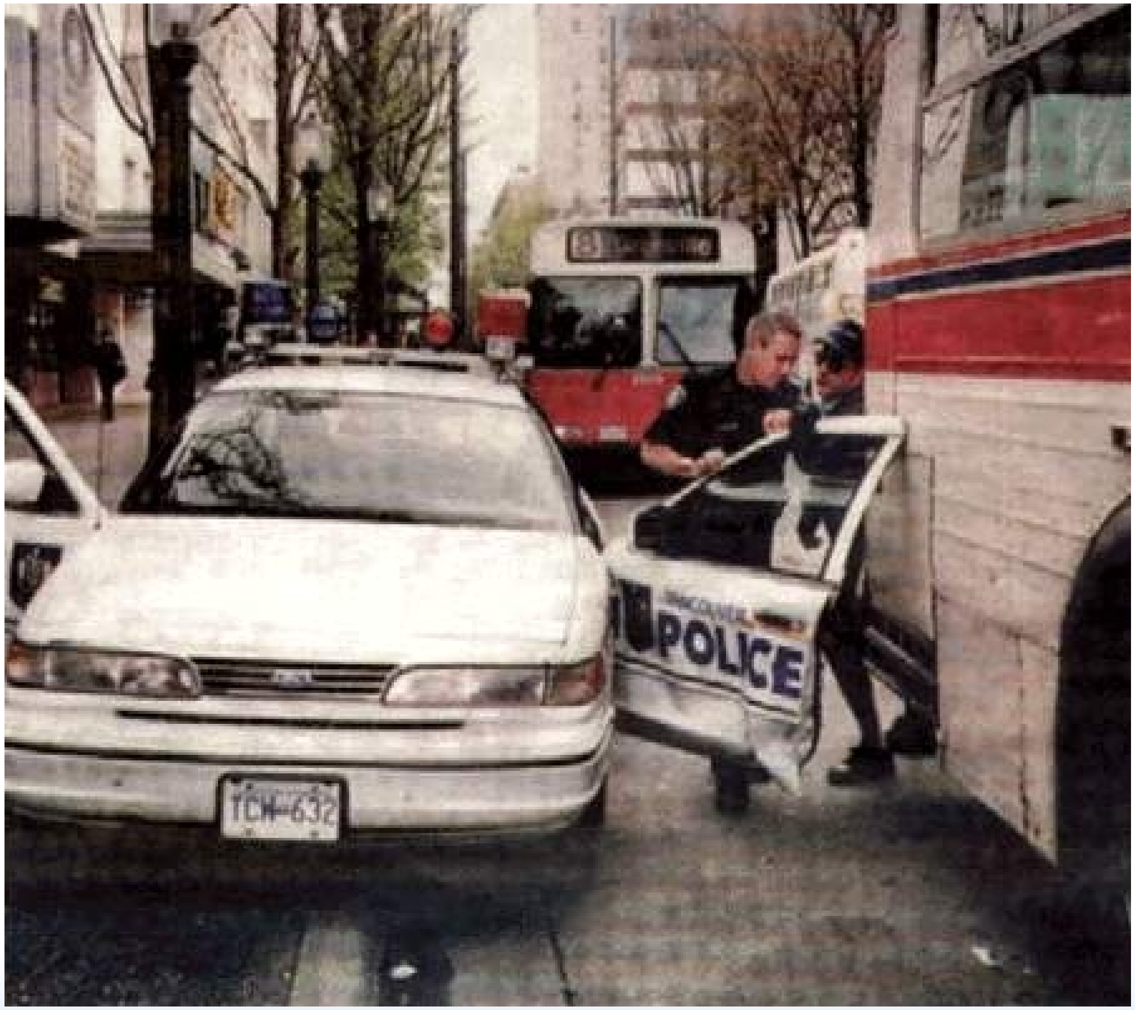
Exercise: Medical Misadministration

Read the two medical misadministration examples in Appendix B

- Identify the errors that were committed
- What caused the errors?
- How might these errors be prevented in the future?

Who’s at Fault?



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Old and New Views of Human Error

Sidney Dekker in *The Field Guide to Understanding Human Error* (2006) suggests that the concept of "human error" may be misleading

The Old View of Human Error: The "Bad Apple" Theory

- Humans are unreliable
- Human errors cause accidents
- Failures come as unpleasant surprises

The New View of Human Error

- Human error is the effect or symptom of deeper trouble
- Human error is systematically connected to people's tools, tasks, and operating environment
- Human error is not the conclusion of an investigation but rather the starting point

Old and New Views of Human Error (cont.)

Dekker suggests that the “old view” oversimplifies

- Somebody didn’t pay enough attention
- If only somebody had caught the error, then nothing would have happened
- Somebody should have put in a little more effort
- Somebody thought that taking a safety shortcut was not such a big deal

The “new view” tries to capture the complexity of the situation

- Safety is never the only goal of a worker
- People do their best to reconcile goals and make trade-offs (efficiency vs. safety)
  - Nobody comes to work to do a bad job!
- A system isn’t automatically safe unless safety is created in the organization—this is the safety culture of the organization
- New tools and technologies introduce new opportunities for errors

Human Error and Safety Culture

Chairman Dale E. Klein's Remarks at the Regulatory Information Conference (RIC), March 10, 2009

Let me touch on a few areas where I think we need to be proactive, rather than passive. The first is safety culture. Let me be clear in saying that the safety record of the nuclear power industry in the U.S. is on the whole very impressive. And despite some problems, there have been measurable, industry-wide improvements in safety.

…But let's not kid ourselves into thinking that everything is fine. We have continued to see incidents over the last few years that indicate that safety culture was not a priority throughout all the staff, at all the plants. In fact, even an excellent plant can have problems because—paradoxically—excellence can have its own risks. An excellent record can sometimes invite complacency, and make it hard to manage expectations.

…One way to combat complacency is to have a clear plan for promoting safety culture. The NRC recognizes that implementing the day-to-day details of safety culture is the responsibility of the licensees. Nevertheless, the agency is taking a more active role.

…Let me emphasize…that we are not doing this to point fingers…Overall, I think while both the NRC and industry have a strong foundation, there is room for improvement. And there are still things I see here and there that resemble complacency. One way to help avoid complacency is through communication and sharing knowledge.

Concluding Thoughts on Human Error

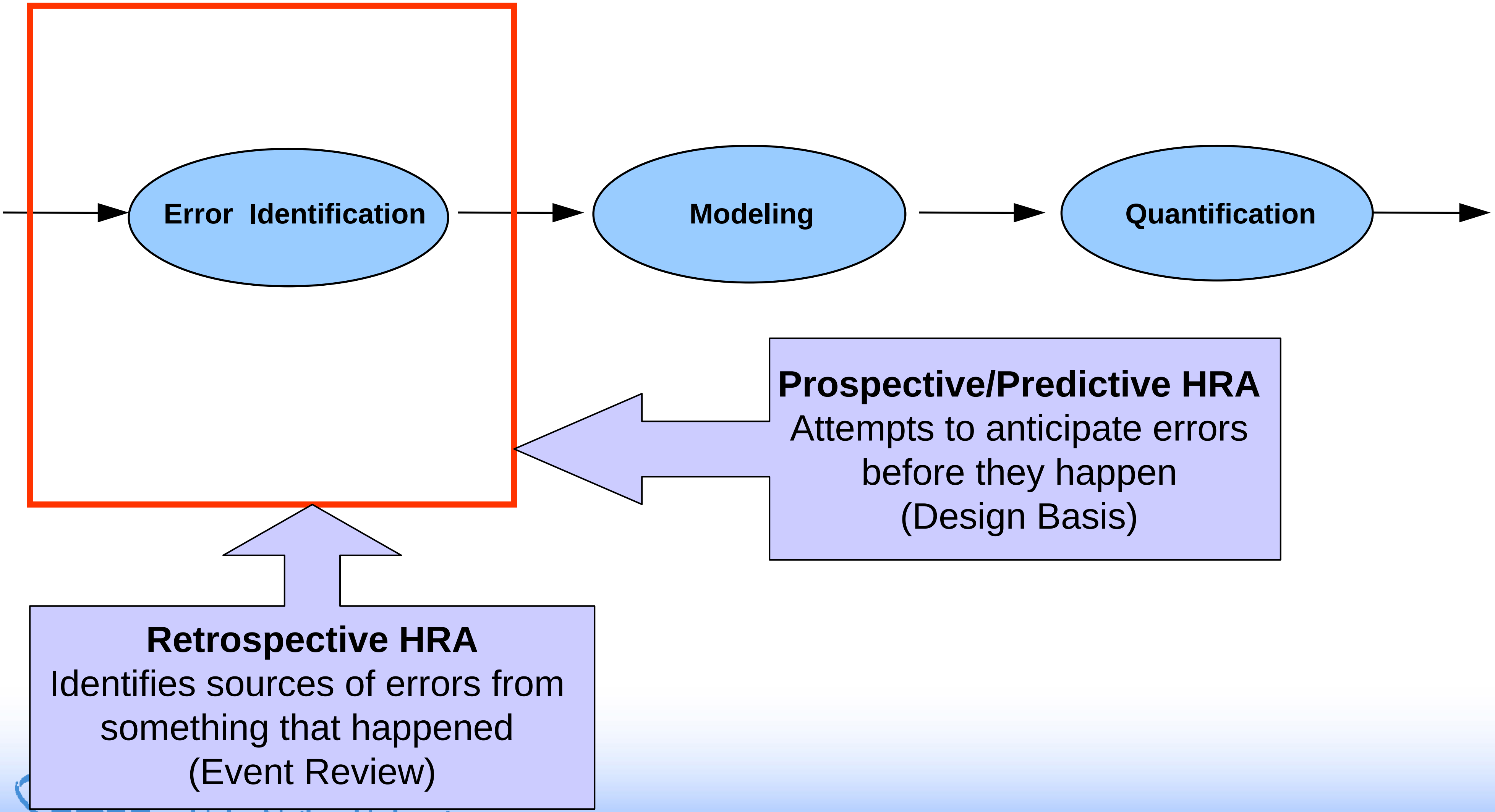
Some Lessons Learned

- Human errors are frequent and significant contributors to accidents and events
- Latent errors contribute as much or more to accidents as do active errors
- Human error is not about blaming individuals; it’s about understanding the situation that led to the error
    - In the remainder of this course, you will learn some of the nuances of identifying, modeling, and quantifying human error and its context

LESSON 3

HRA Identification Phase

Requirements for Human Reliability Analysis



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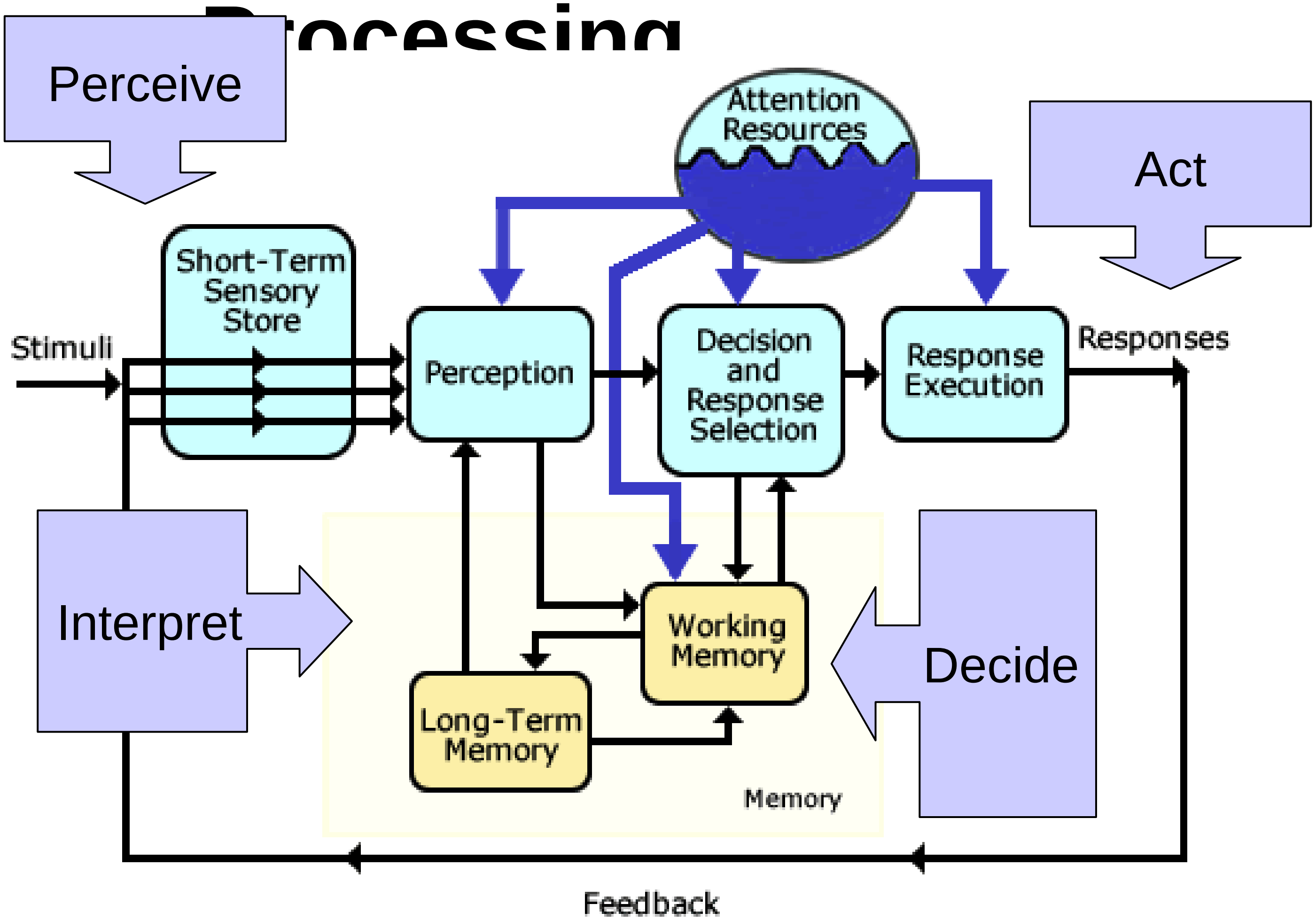
Opportunities for Errors

Humans are complex systems that must:

- perceive
- interpret
- decide courses of action
- carry out those actions

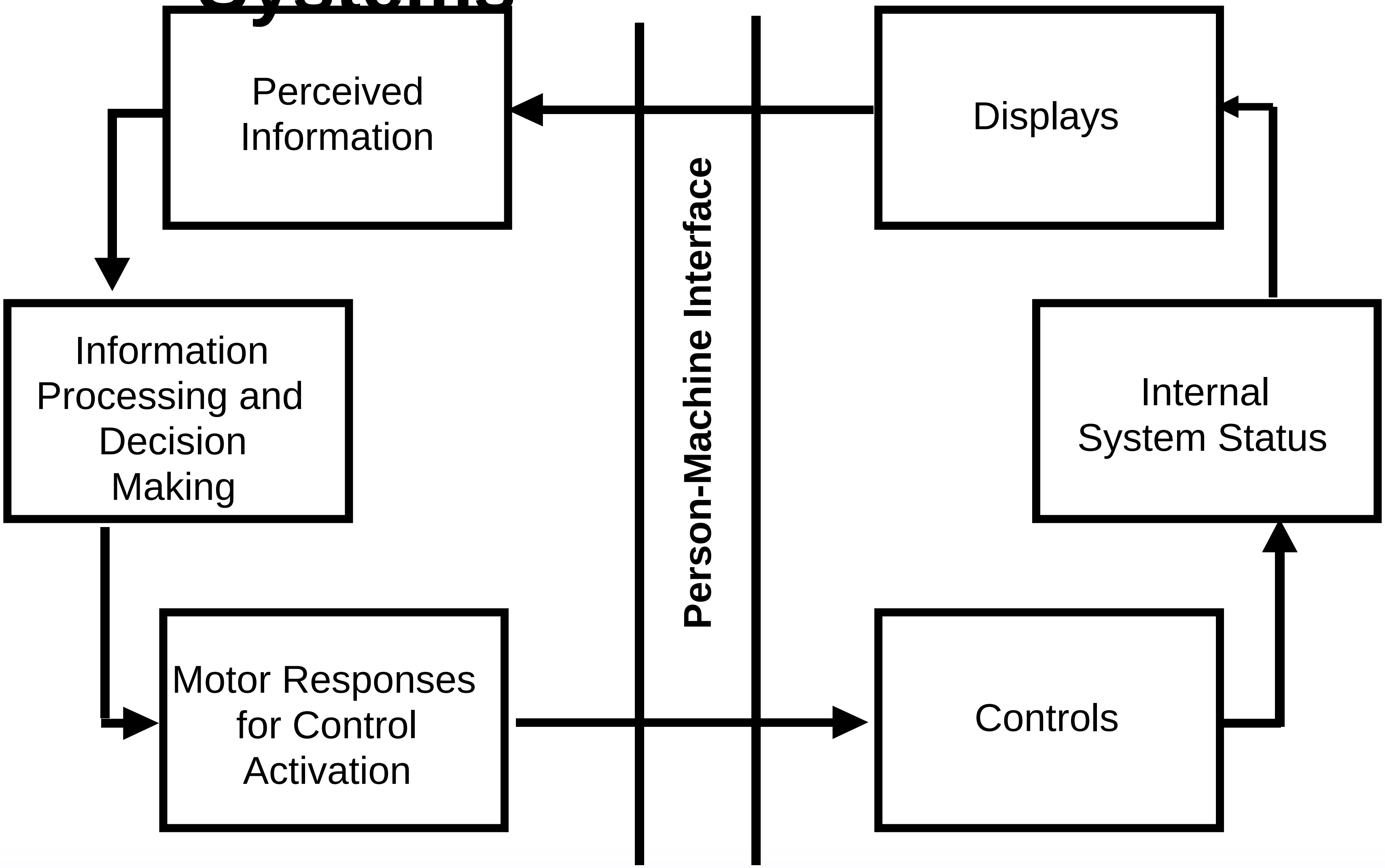
Each of these functions present opportunities for errors.

Human Information Processing



Wickens' Model of Information Processing

Human-Machine Systems



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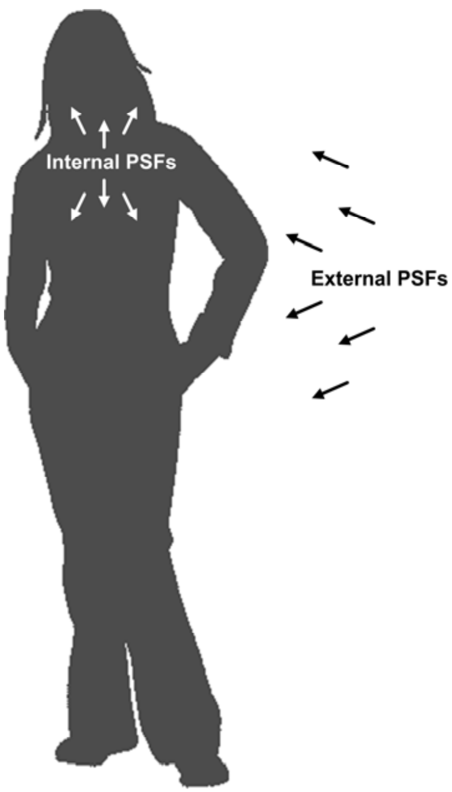
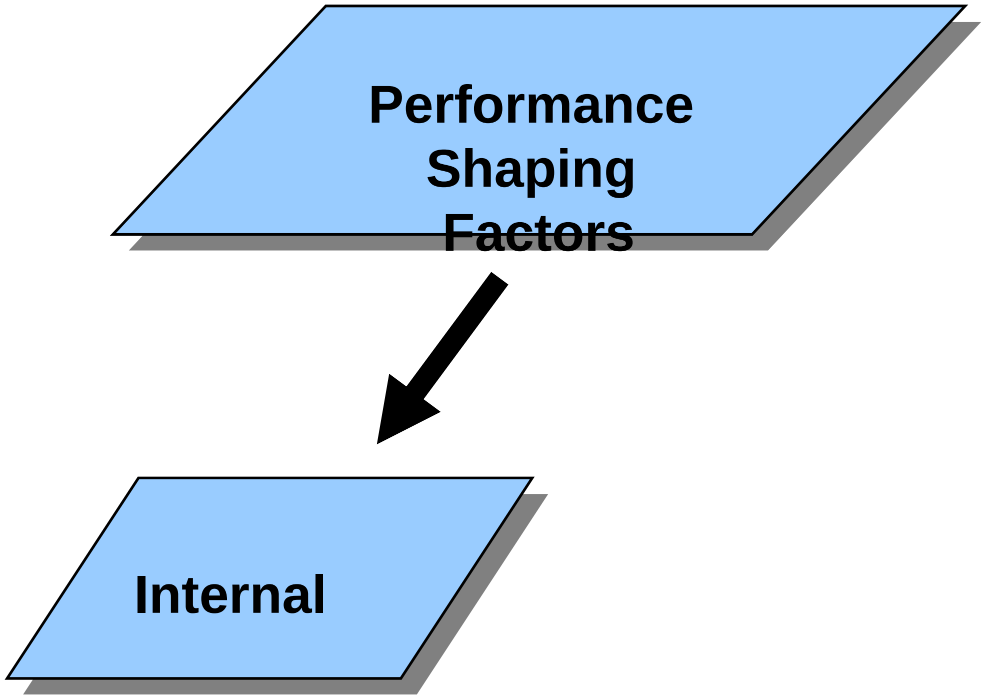
Performance Shaping Factors

Those factors that influence the performance and error likelihood of the human are called **performance shaping factors** (PSFs).

PSFs may be internal or external

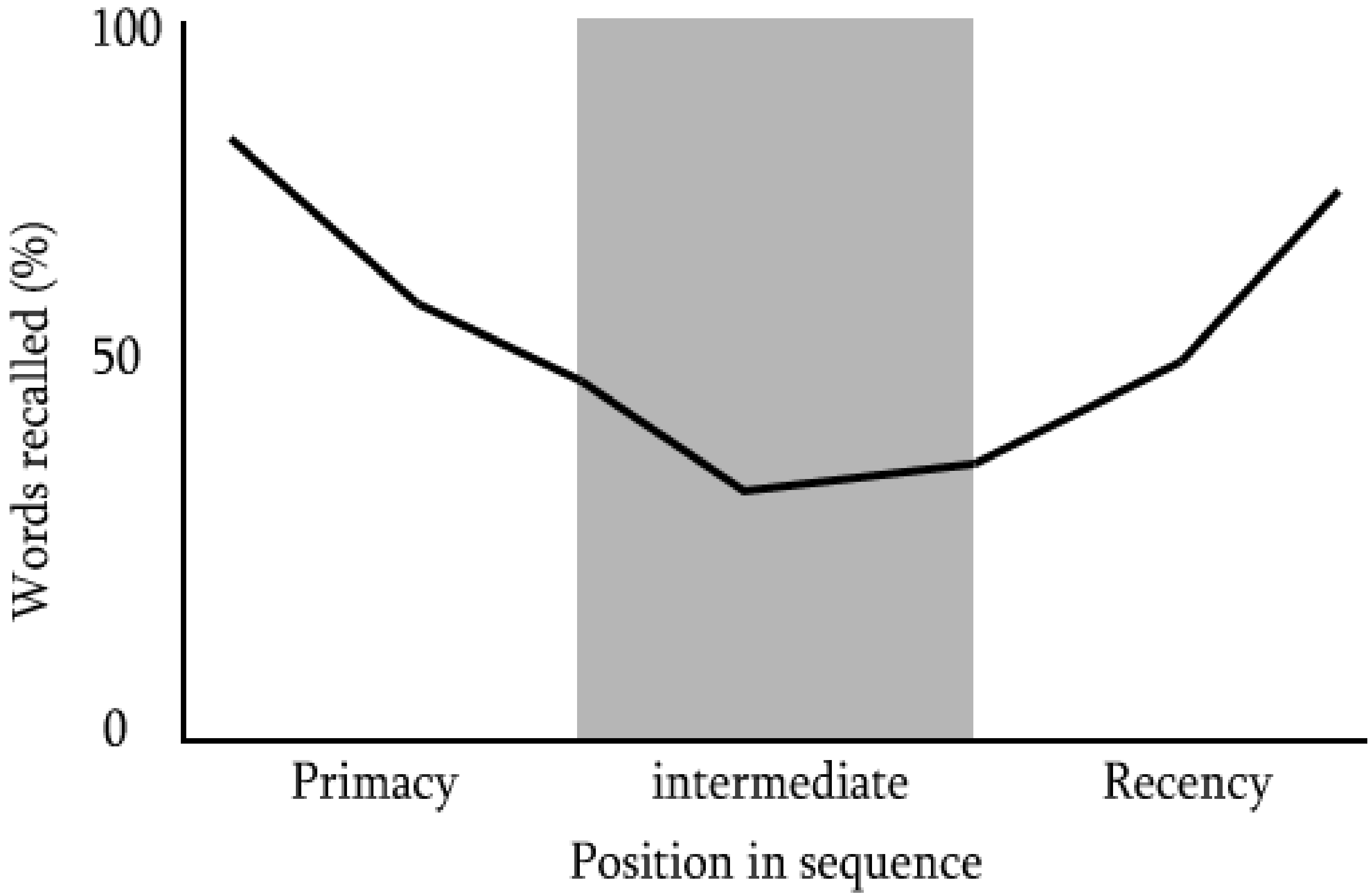




Internal PSFs are human attributes, such as skills, abilities, and attitudes, that operate within the individual, and which are brought to the job by the individual.

Exercise on human short-term memory ability (or lack thereof): Take out a blank sheet of paper. Listen to the list that the instructor reads to you. When the instructor has finished reading the list, quickly write all the items you can recall on the piece of paper.

Which Items are Recalled?

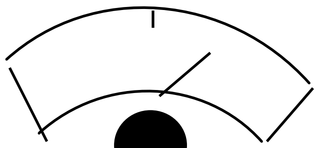


Psychological Context

Is created by individuals based upon

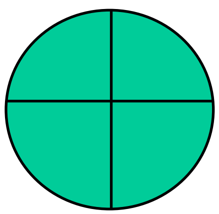
- their prior knowledge
- their expectations
- their present circumstances
- their goals
- the reward/punishment structure

Exercise: Population Stereotypes

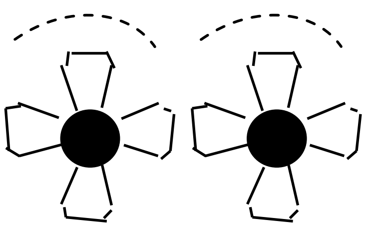


Knob

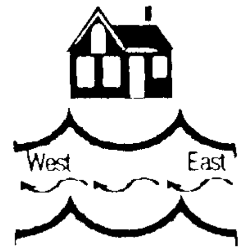
1. To move the arrow-indicator to the center of the display, how would you turn the knob?
_______________ clockwise
_______________ counterclockwise



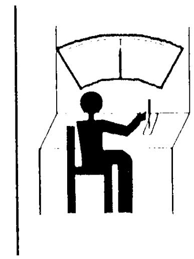
2. In what order would you label the 4 quadrants of a circle. Write in the letters A, B, C, D, assigning one letter to each Quadrant.



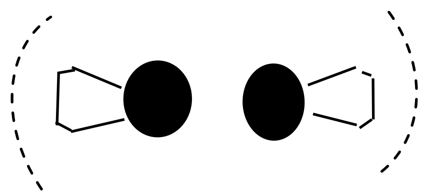
3. Here are 2 knobs on a bathroom sink, looking down at them. Put an arrow on each dotted line, to show how you would use them to turn the water on.



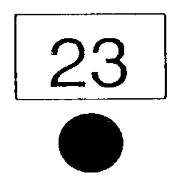
4. Here is a river flowing from east to west. Is the house on the
_____________ left bank?
_____________ right bank?



5. To move the arrow indicator to the right of the display, how would you move the lever?
____________ Push
____________ Pull

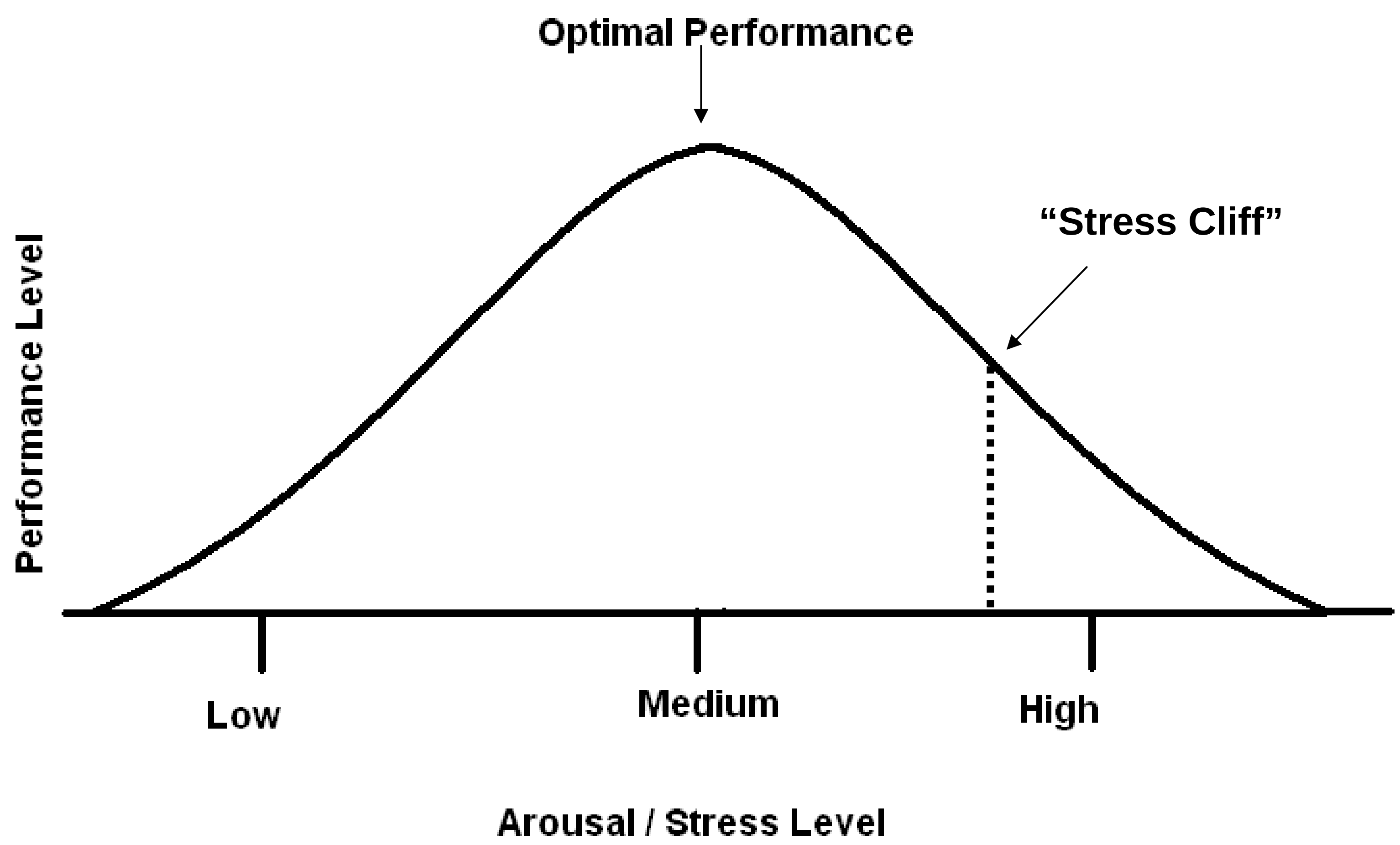


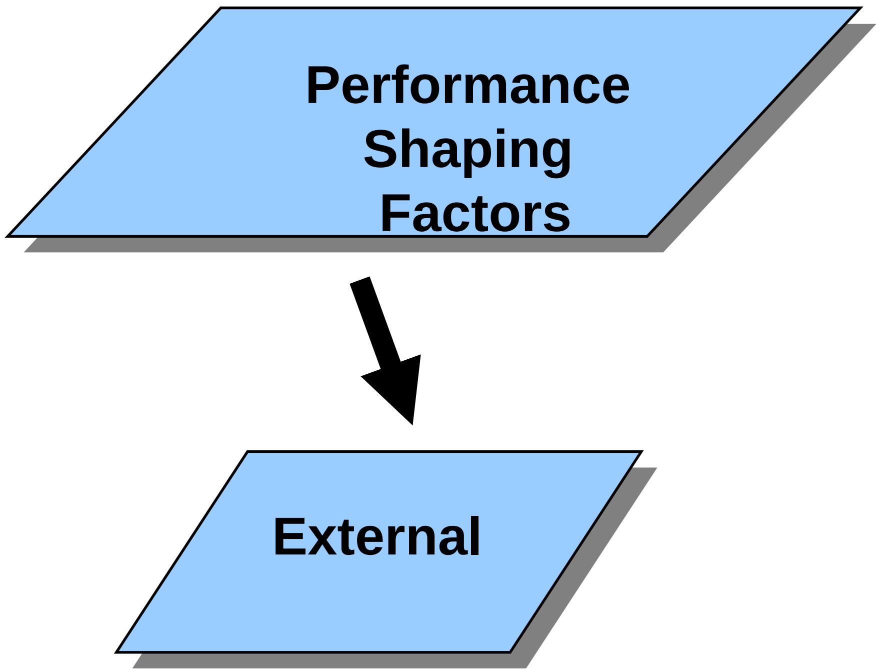
6. Here are two knobs on a bathroom sink, looking down on them. Put an arrow on each dotted line, to show how you would operate them to turn water on.



7. To increase the number in the displayed window, how would you turn the knob?
____________ clockwise
____________ counterclockwise

Example: Stress as an Internal PSF





External PSFs are aspects of situations, tasks, and equipment characteristics that influence performance.

Example: Noise as an External PSF

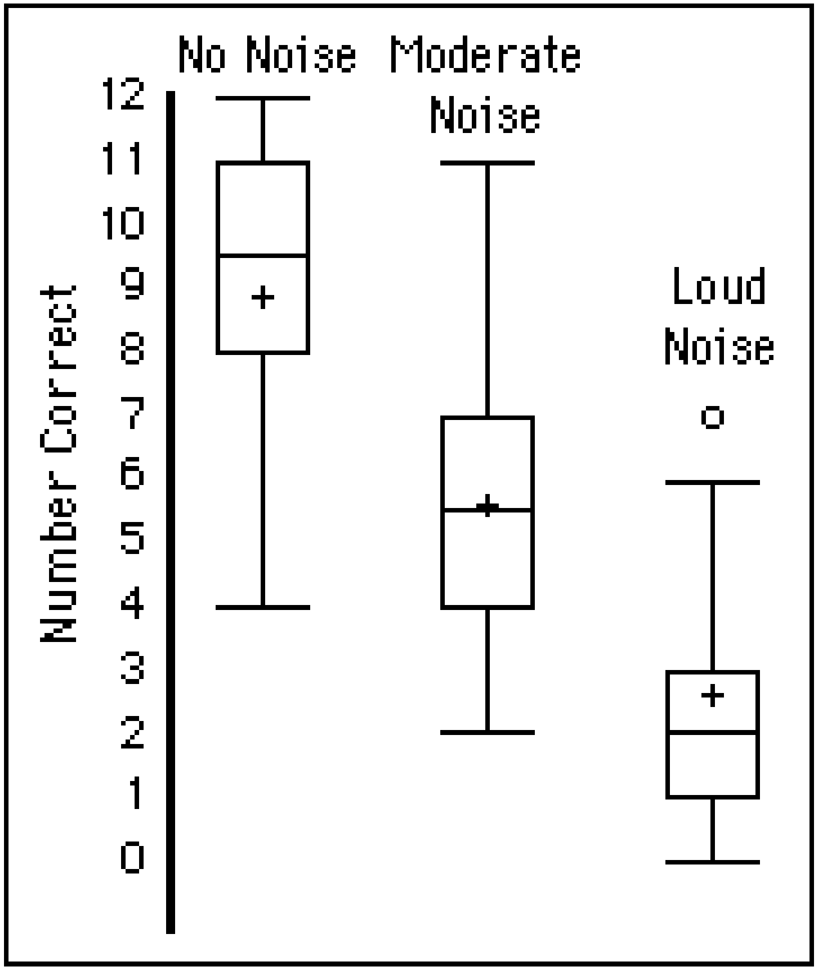
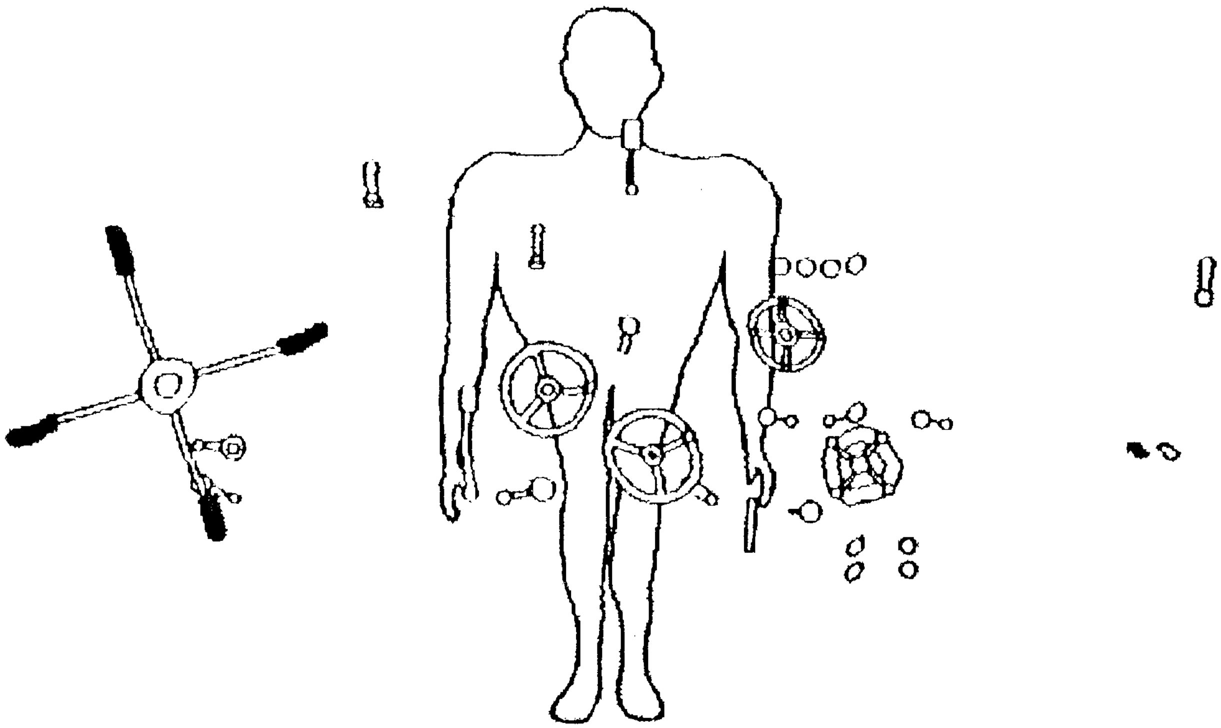


Figure 1. Box plots of the data for the three conditions.

Example: Ergonomics as an External PSF



The controls of this lathe, in current use, are placed so that the ideal operator should be 4.25 ft. tall, 2 ft. across the shoulder, and have an 8 ft. arm span!

Exercise: What internal and external PSFs do you think may have been involved in this accident?

Good Practices PSFs

NUREG-1792 identifies Good Practices for HRA

- Also identifies PSFs that should be considered in a quality HRA

Good Practices PSFs (NUREG-1792)
Training and Experience
Procedures and Administrative Controls
Instrumentation
Time Available
Complexity
Workload/Time Pressure/Stress
Team/Crew dynamics
Available Staffing
Human-System Interface
Environment
Accessibility/Operability of Equipment
Need for Special Tools
Communications
Special Fitness Needs
Consideration of 'Realistic' Accident Sequence Diversions and Deviations

"Other"

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Exercise: PSF Exercise

1. Divide into groups.

2. Problem definition: List all the performance shaping factors that may influence the reliability of an everyday task like driving to work.

3. For each performance shaping factor, identify and describe the mechanisms of how that factor affects the performance of the task.

4. Describe how you might measure those factors.

Taxonomies of Human Error

Taxonomy

- Systematic grouping according to laws and or principles
- Different HRA methods have different taxonomies

Benefits

- Aids analysts in identifying errors
- Ensures consistency in performance characterizations
- Helps analysts determine the underlying reasons for the error

We will examine three taxonomies:

- Swain and Guttman's Taxonomy (Commission/Omission)
- Rasmussen's Cognitive Taxonomy (Skill/Rule/Knowledge)
- Reason's Error Taxonomy (Slips/Lapses/Mistakes)

Swain and Guttman's Taxonomy (1983)

Errors of omission

- Fail to do something required

Errors of commission

- Do something you shouldn't do

Sequence errors

- Do something in wrong order

Timing errors

- Do something too slowly or too quickly

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Rasmussen's Cognitive Taxonomy (1979)

Skill-based behavior

Rule-based behavior

Knowledge-based behavior

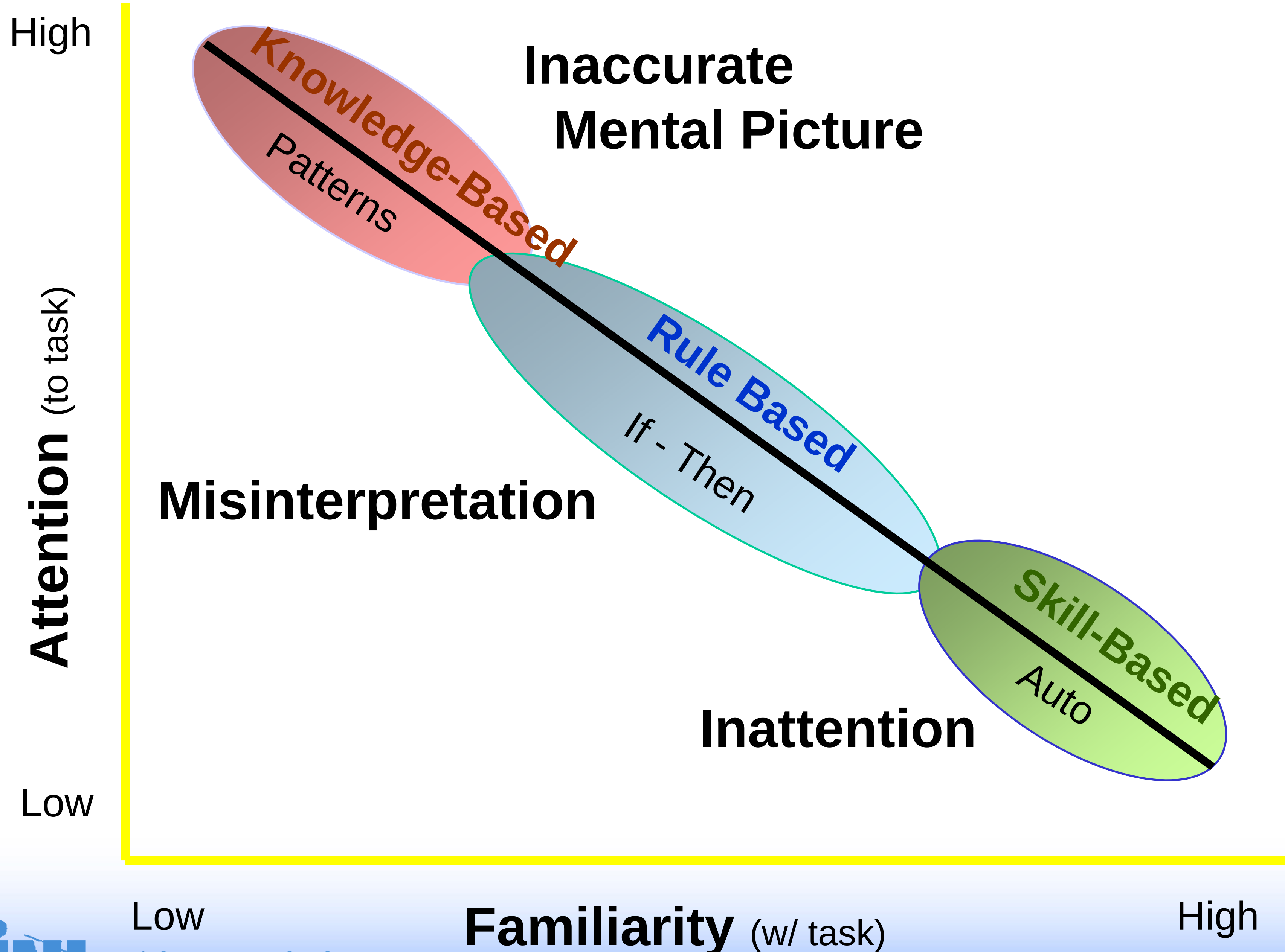
Behavioral Continuum

Skill-based = behavior that requires very little or no conscious control to perform or execute an action once an intention is formed (think: highly skilled and automatic)

Rule-based = the use of rules and procedures to select a course of action in a familiar work situation (think: following procedures)

Knowledge-based = type of control that must be employed when the situation is novel and unexpected (think: operators have to rely on problem solving, which requires a lot of resources; they are not old pros at this)

Performance Modes



Source: James Reason. *Managing the Risks of Organizational Accidents*, 1998.

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Reason’s Error Taxonomy (1980)

Slips

- Good intentions, right mental model, but do something wrong
- An error of commission

Lapses

- Good intentions, right mental model, but fail to do something
- An error of omission

Mistakes

- Good intentions, wrong mental model

Violation

- Willful circumvention
- Not necessarily violation in the sense of malevolent intent; can also be “heroism” or “mentality of there’s a better way to do something”

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Exercise on Taxonomies

Select an appropriate classification for each of these errors:

1. An operator turns off an automated control system.
2. A worker fails to clean out filings after installing a new pipe fitting.
3. A disgruntled electrician reverses two wires on a switch.
4. A painter leaves an emergency diesel generator inoperable after an outage.
5. An operator fails to identify a steamline break immediately due to a missing alarm.
6. A coworker enters a radioactive area without proper protective gear to remove an injured worker.
7. The crew responds incorrectly initially to a plant upset that isn't covered in the procedures.
8. A carpenter lacerates his leg with a circular saw during maintenance activities.
9. Spent fuel personnel do not check to see if the lid is seated properly on a spent fuel canister.

Task Analysis

A technique to help identify human activities in a task

- These activities may serve as the starting point for identifying potential human errors
- Think of it as the steps in a procedure of human actions, even though there may be no formal procedure
- May have different levels of task decomposition
  - Can model high-level tasks such as everything related under a common task goal (e.g., turn it off)
  - Can model low-level tasks such as all activities required (e.g., identify switch, turn switch to off position, verify it is off by disappearance of green "on" light)

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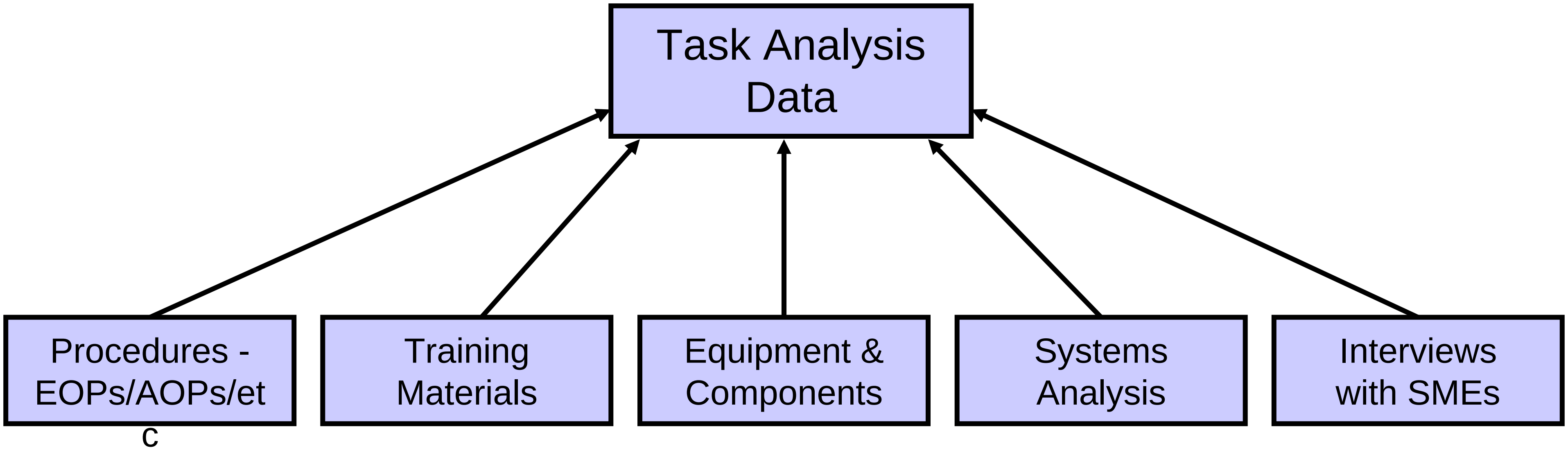
Task Analysis Used to Identify Actions and Decisions



EOP = emergency operating procedure, AOP = abnormal operating procedure, SME = subject matter expert

Task Analysis Steps

- Capture each major decision or decision-action in the sequence of human and hardware activities
- Human actions may be clustered according to a high-level goal (e.g., “seal cask”) with subgoals
- It is useful to treat these as successful or safe human actions vs. unsuccessful or unsafe human actions
- It is often useful to treat these as a chronological sequence of actions
  - For event investigation, this would be a timeline
  - For prospective risk modeling, this would simply be a consideration of the risk significant activities that take place in plant operations
- Possible or actual human errors are called **Human Failure Events (HFEs)**

Task Analysis Exercise

- Develop a task analysis (i.e., identify the steps/ sequence required) for earlier exercise of "driving to work"
  - Hint: think safety-critical functions, performance, etc.
  - Identify any new performance shaping factors revealed by this task analysis
  - Report out and discuss

Initiating Events

Event initiators:

- Help focus the HRA and task analysis
  - Human activities are pre-initiator, initiator related, or post-initiator
- Provide sequences and conditions that are generally provided by the Risk Assessment analyst
- Are categorized as:
  - Human actions (errors)
  - Hardware failures
  - Software failures
  - External events

Reactor Initiating Events

- NUREG/CR-4550, Vol. 1, Rev 1, Jan 1990, pg 3-1, defines initiating events as "those events that disrupt the normal conditions in the plant and lead to the need for reactor subcriticality and decay heat removal."
- NUREG/CR-5750, "Rates of Initiating Events at US Nuclear Power Plants: 1987-1995," Feb 1999, page 6, defines the initial plant fault (read initiating event) as "the first event in a sequence of events causing or leading to an unplanned, automatic, or manual reactor trip.“
- NUREG/CR-6928, “Industry-Average Performance for Components and Initiating Events at U. S. Commercial Nuclear Power Plants,” Feb. 2007. Uses same definition as NUREG/CR-5750 in most cases, but updates frequency estimates.
- Generally speaking: An off-normal event, that left unattended (i.e., no response from operators or automatically actuated systems), would result in an undesired outcome. For nuclear power plants the typical undesired outcome is core damage, but it may also be release of radioactive materials outside the boundaries of the facility (exposure to the public).

NMSS Example: Initiating Events for Spent-Fuel Pool Risk Analysis

- Loss of offsite power from plant-centered and grid-related events
- Loss of offsite power from events initiated by severe weather
- Internal fire
- Loss of pool cooling
- Loss of coolant inventory
- Seismic event
- Cask drop
- Aircraft impact
- Tornado missile

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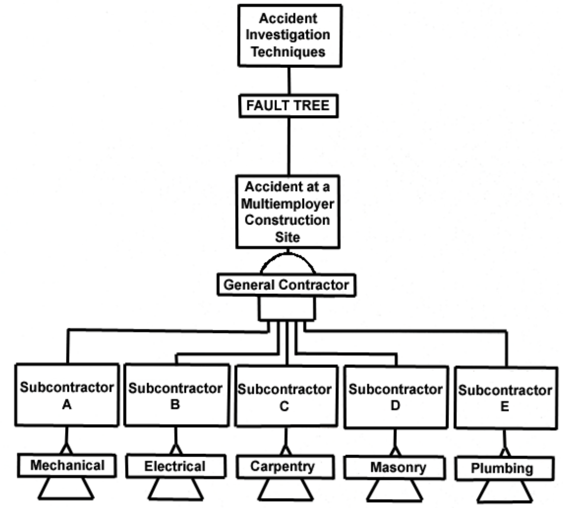
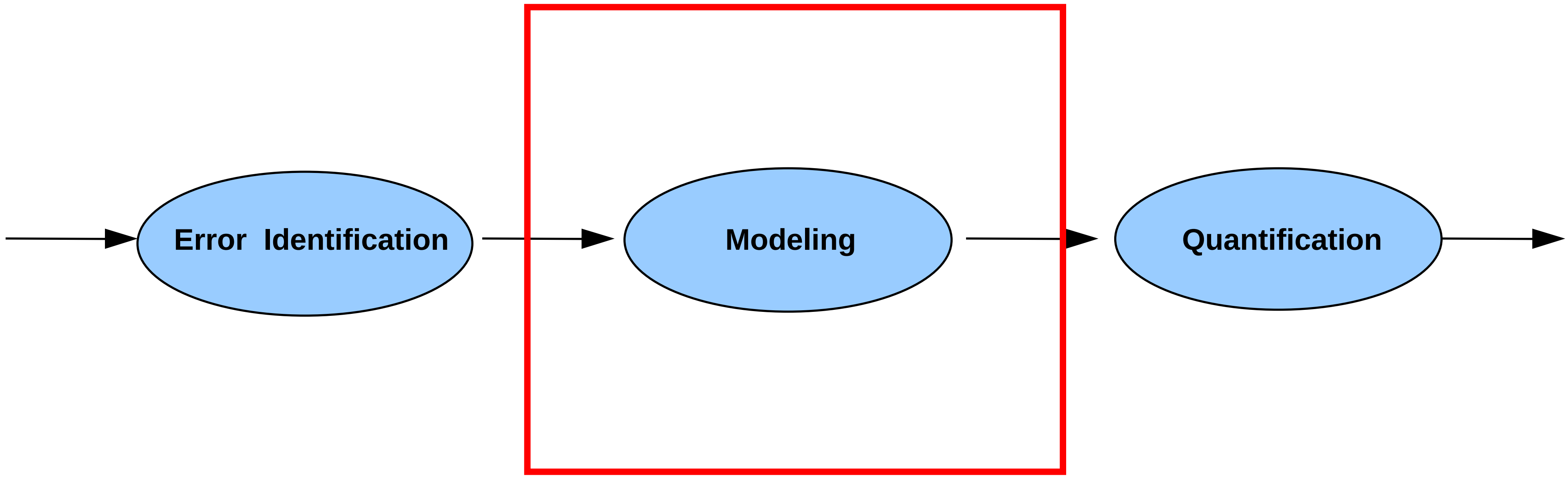
LESSON 4



HRA Modeling Phase

The essential HRA processes that are integrated into PRAs - HRA Modeling



Modeling Human Actions

What comes after error identification?

- The human activities identified in the first phase of HRA are then modeled in the PRA

Recall, that a Human Failure Event (HFE) is:

- 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 human action

Tying HRA Models to System PRA Event and Fault Trees

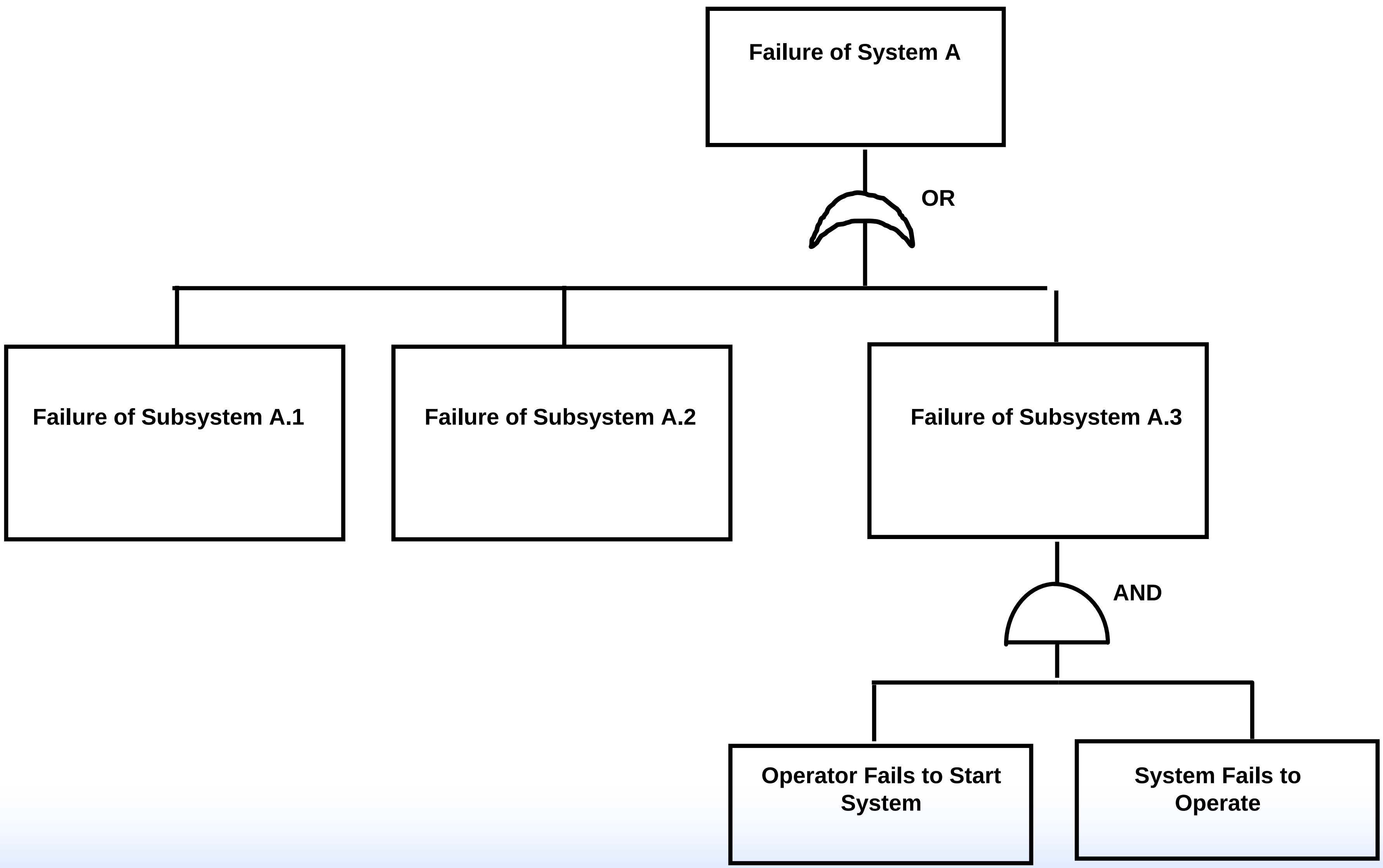
Basic human events in PRA event and fault trees may

be:

- At sufficiently low level for quantification (no further analysis is necessary)
- At a high level

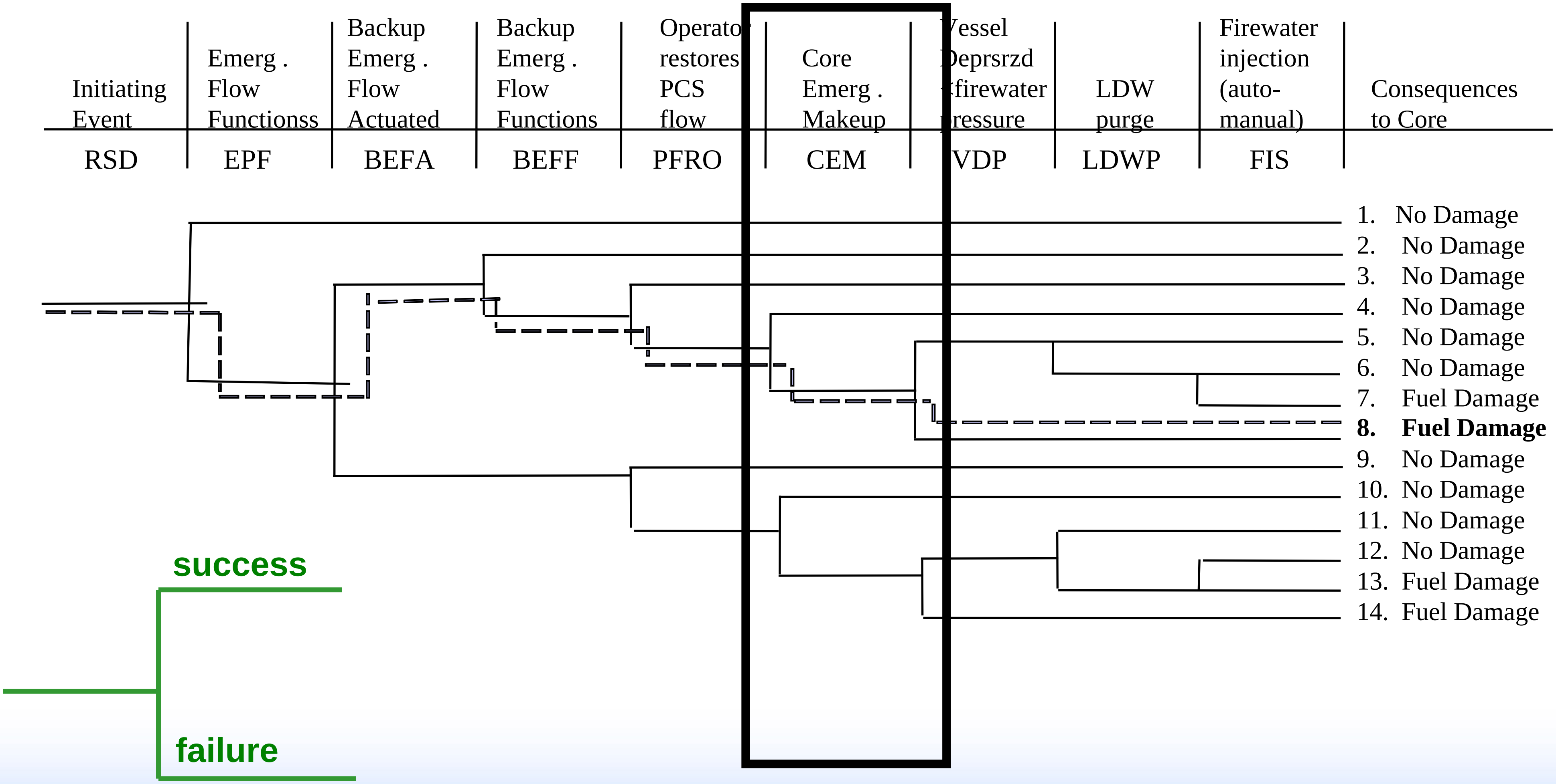
  If conservative screening values (e.g., human error probability = 0.5) applied to fault trees indicate that a high level human event impacts the overall analysis, there is good justification to perform more detailed modeling and quantification

Generic System Fault Tree Example



System/Operator Event Tree

High-level basic human action/event
further analysis may be important



Standard HRA Modeling Techniques

- HRA Event Trees
- Fault Tree
- Other techniques more applicable to qualitative analyses:
  - Influence Diagrams
  - Event Sequence Diagrams

Types of Elements Modeled

- Correctly performed activities (success)
- Activities leading to failure
- Sequences of failures and successes
- Recovery actions that catch and fix errors before they lead to failure

Recovery Actions

- In PRA, recovery may refer to functional recovery
- In HRA, recovery actions are those actions taken by equipment or humans that correct a failure of another action.
  - Second Checker
  - Alarms
  - Automatic Safety Systems

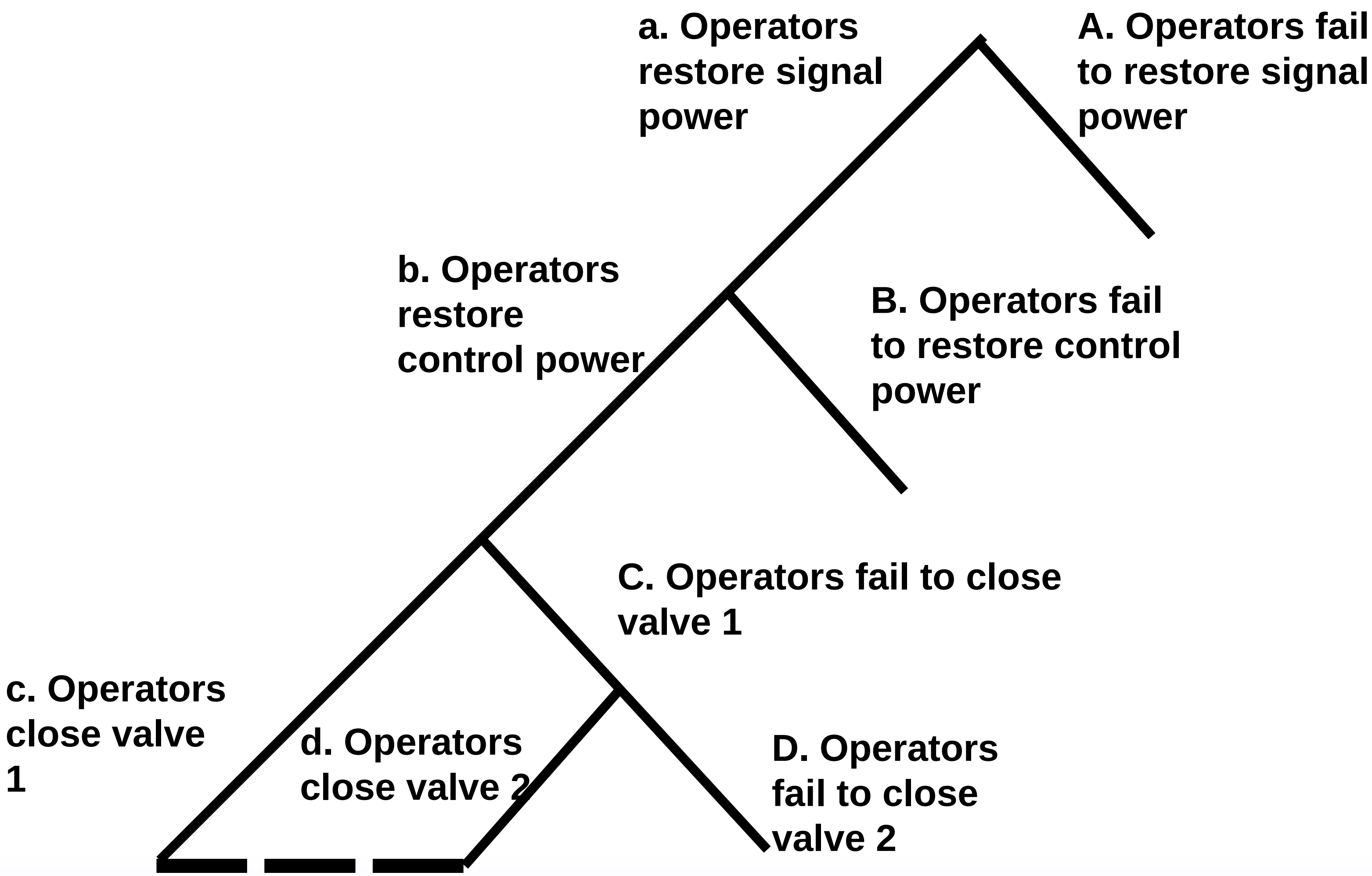
Bounding and Assumptions

- The context and assumptions affecting the modeling should be stated explicitly
- Bounding is always needed—impossible to include it all
  - How much detail is desirable? (Relates to purpose of analysis or phase--screening vs. realistic)
  - What events, steps, and failures should be included?

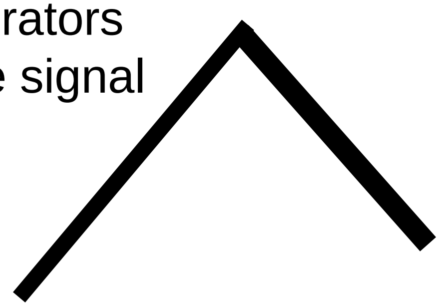
HRA Event Tree

- Developed by Swain and colleagues at Sandia
- Documented in Technique for Human Error Rate Prediction (THERP: NUREG/CR-1278)
- No longer widely used (PRA event and fault trees used more frequently), but has uses:
  – Captures recovery information well
  – Allows clear delineation of probability of success and probability of failure/error
  – Shows sequence of actions better than fault trees

Sample HRA Event Tree



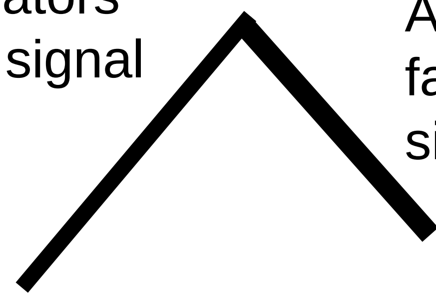
An HRA event tree consists of one or more binary branches (correct/incorrect actions)



Left branches show successful actions

Use small letters for success branches

a. Operators restore signal power



A. Operators fail to restore signal power

Right branches show failed actions

Use CAPITAL letters for failure branches

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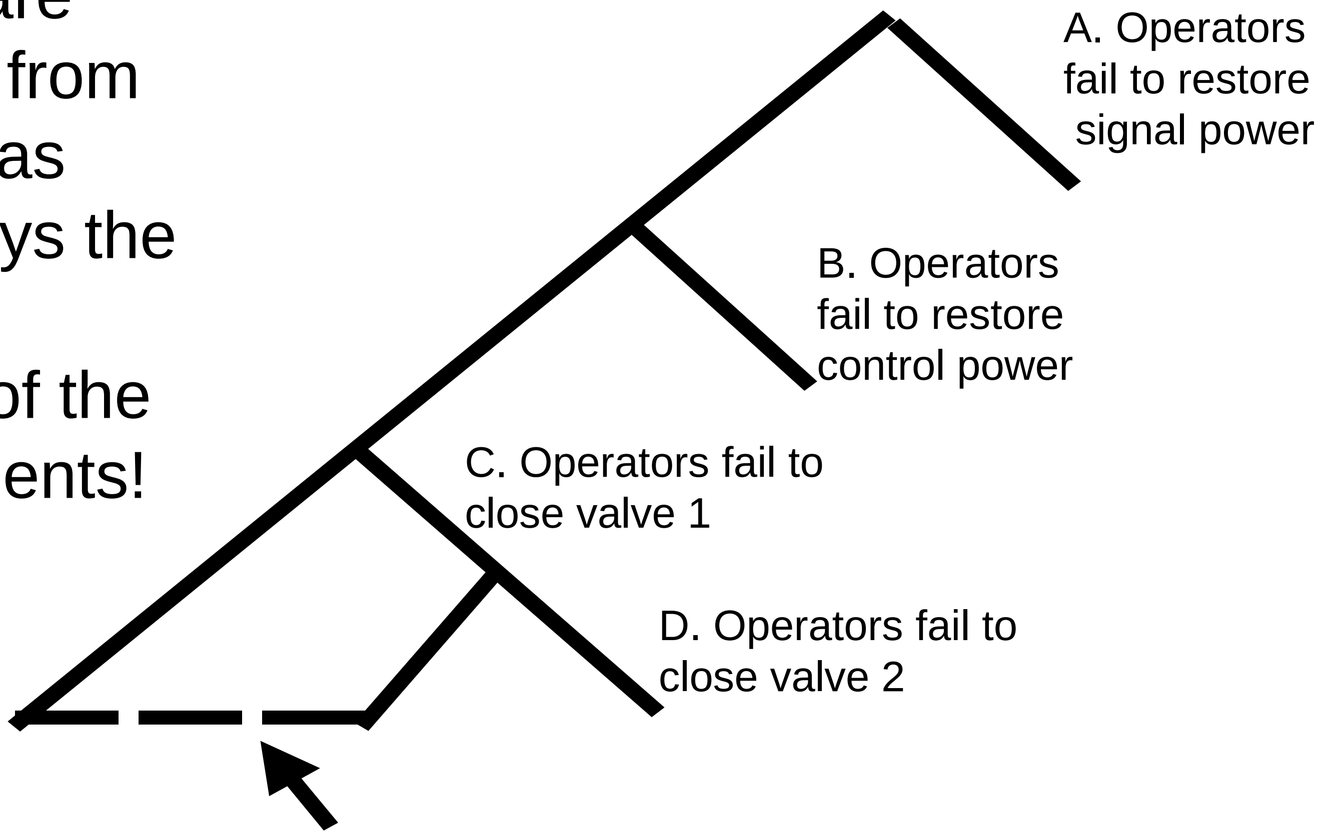
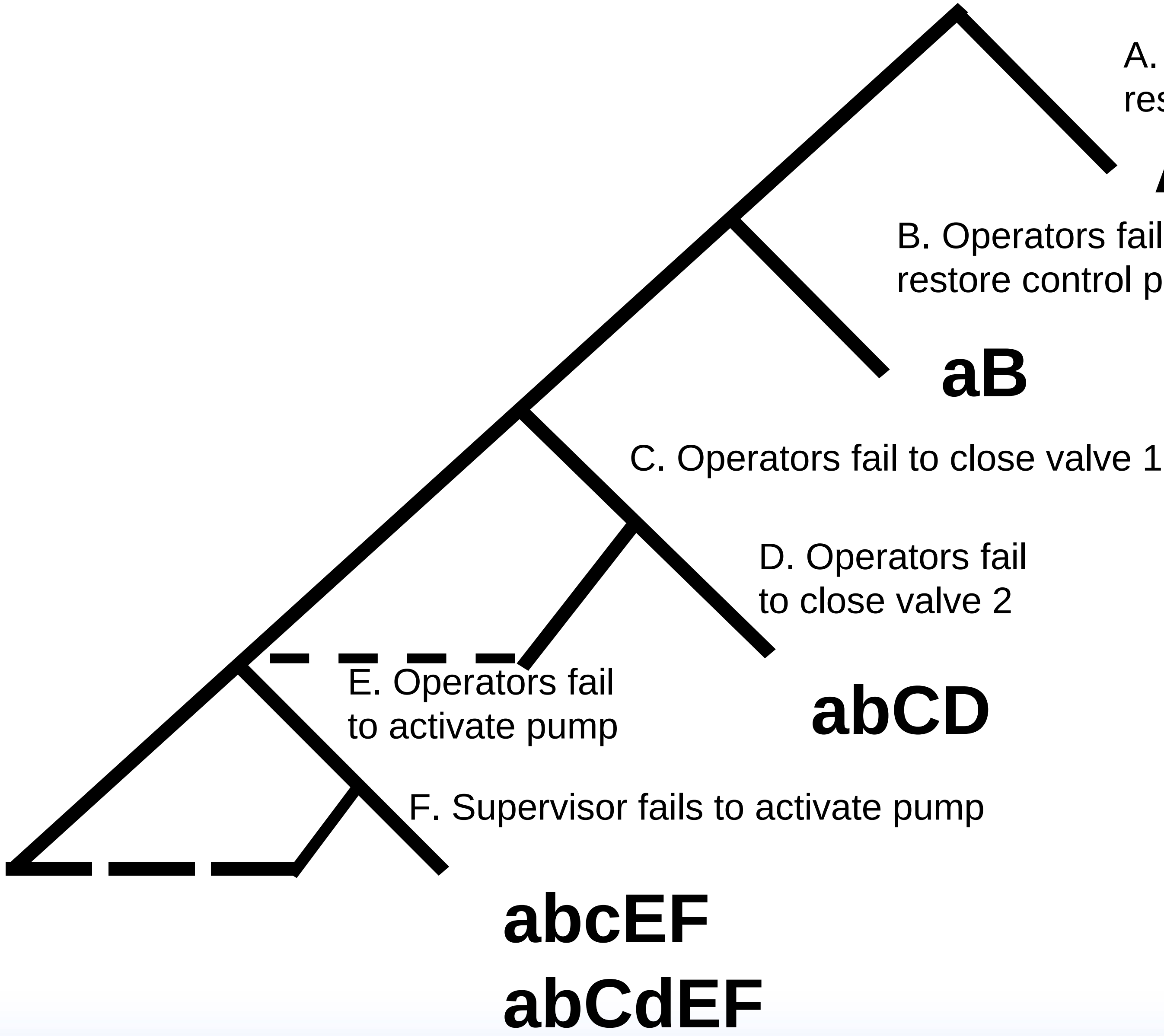
Success branch descriptions are often omitted from tree diagram as they are always the successful complement of the failure statements!

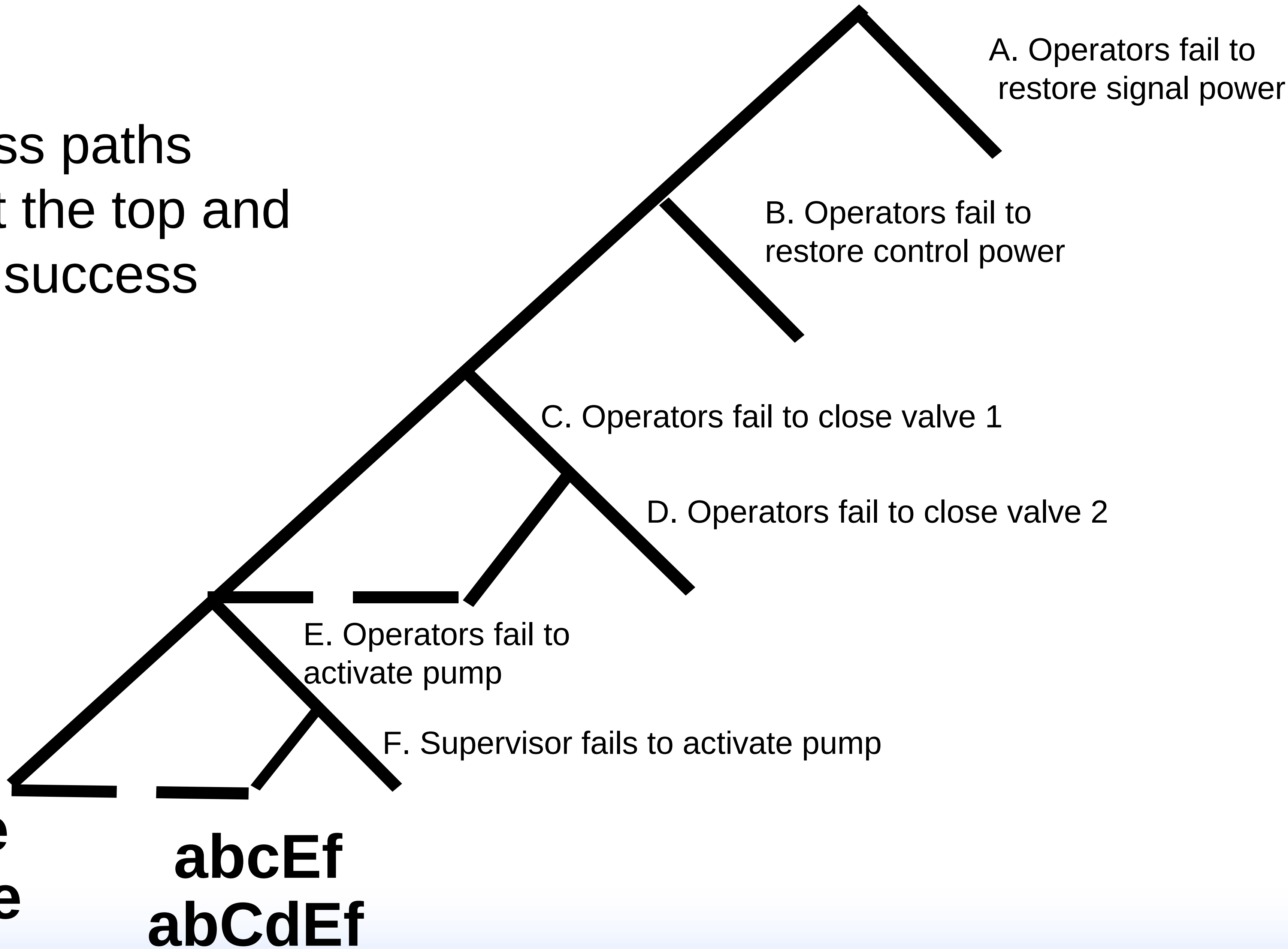


Recovery is shown as dashed line after some failure back to a success path



A failure path is a path starting at the top of the tree that <u>ends</u> in failure (i.e., **A, aB, abCD, abcEF**, and **abCdEF** are all failure paths for this tree.)

Success paths start at the top and end in success



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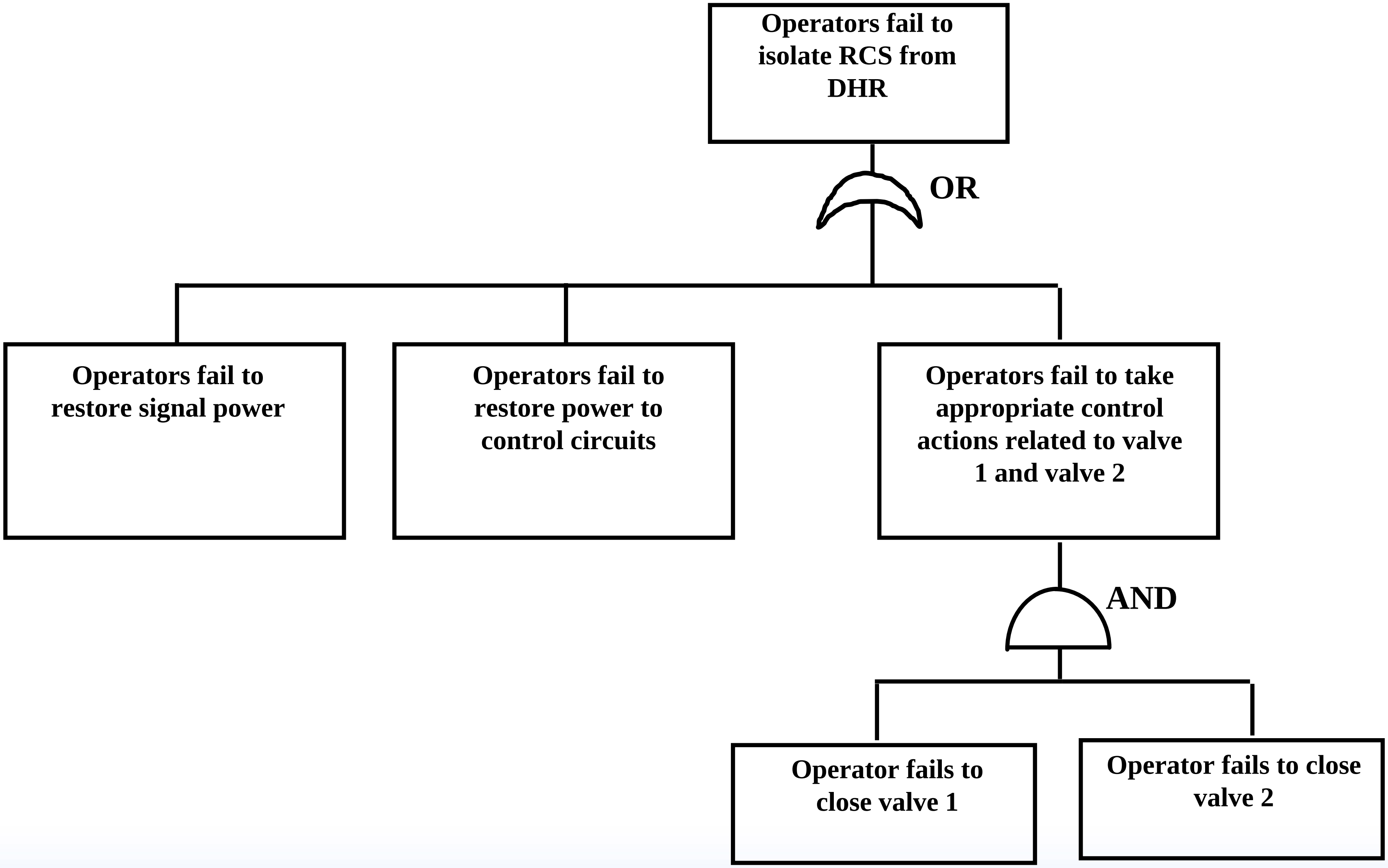
Sample HRA Fault Tree



HRA Fault Trees

- Can be used to represent the same human actions and logical structures as HRA event trees
- Particularly useful in emphasizing the structure of *AND* and *OR* logic
- Unlike HRA event trees, HRA fault trees do not do a good job of showing *sequence*

Exercise: HRA Fault Tree and HRA Event Tree

- Review your earlier example of driving to work
- Identify one or two human failure events for the activity, and draw a fault tree and an event tree
- Report out and discuss

Integrating HRA into PRA Modeling

Major Approaches for Integrating HRAs into PRAs

- SHARP/SHARP1
- IEEE 1082/D7 (1997)

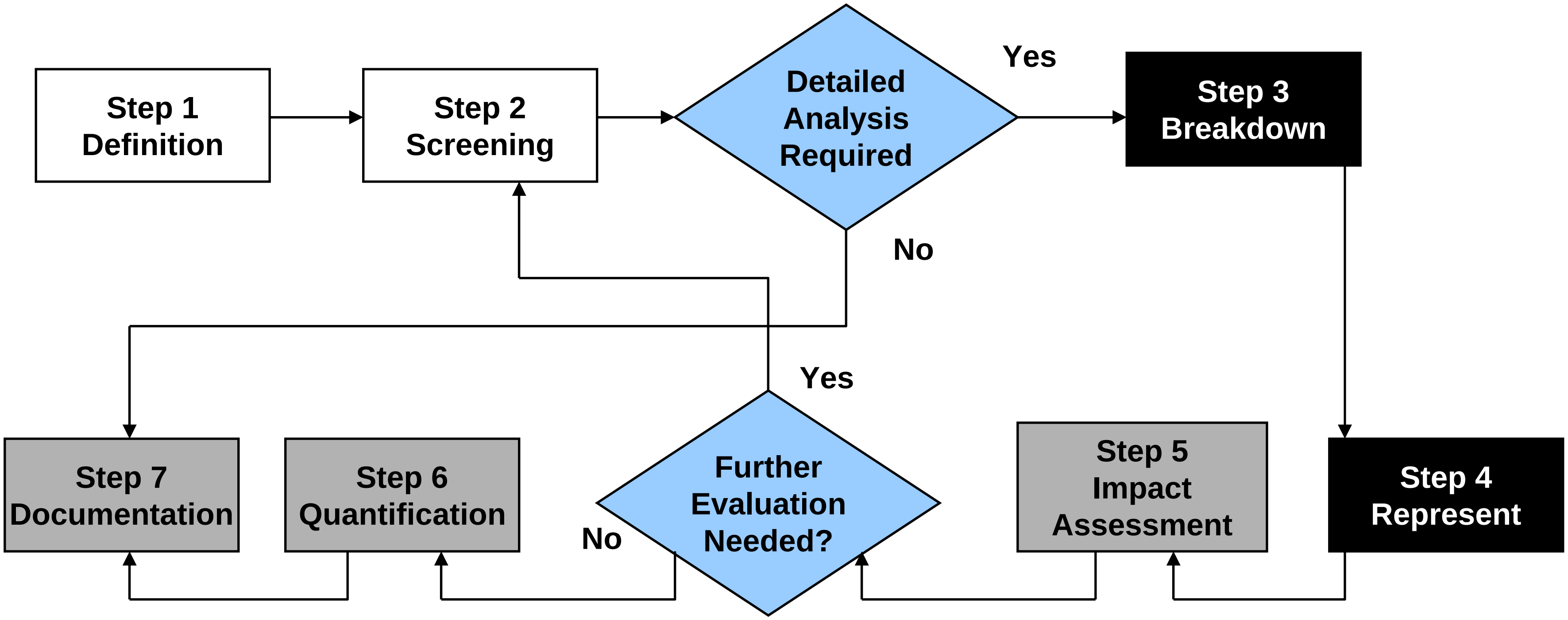
Approaches Emphasize That:

- HRA is a part of entire PRA process
- HRA personnel should be included in team
- Screening precedes selected detailed analyses
- Phases include identification, modeling, and appropriate quantification as well as documentation
- Different methods may accomplish the same thing

Systematic Human Action Reliability Procedure (SHARP1)

- Originally developed by EPRI in mid 1980s
- Foundation for other methods
- Involves 7 basic steps and 2 decision points
  - System analysts responsible for 2 steps
  - HRA analysts responsible for 2 steps
  - Shared responsibility for 3 steps

The SHARP Process



Steps 1 and 2 = Systems Analyst
Steps 3 and 4 = Human Reliability Analyst
Steps 5, 6, and 7 = Both

IEEE STD 1082 (1997) – Guide for Incorporating Human Action Reliability Analysis for Nuclear Power Generating Stations

- Concise document (see course CD for a copy)
- Provides general framework for integrating HRAs into PRAs
- Describes outputs and decisions entailed in the 8 steps
- Emphasizes the importance of team training

IEEE 1082 Steps

1. Train the team
2. Familiarize team with plant
3. Build initial plant model
4. Screen human interactions
   – Decision Point (Is event significant?), If no go to #7
5. Characterize human interactions
6. Quantify human interactions
   – Decision point (Is sequence recoverable?) If yes, go to #5
7. Update plant model
8. Review results

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#5—Characterizing Human Interactions

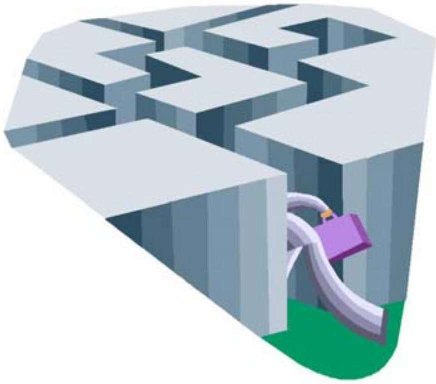
- Type, location and design of controls/displays
- Feedback type, sensory mode, delay, and frequency
- Characteristics of procedures used
- Task loading for control room personnel in worst case conditions
- Management and organization and supervision for maintenance
- Quality, content, frequency, and specificity of training
- Worker competency relevant to PRA scenarios

Summary of Integrating HRA in PRA

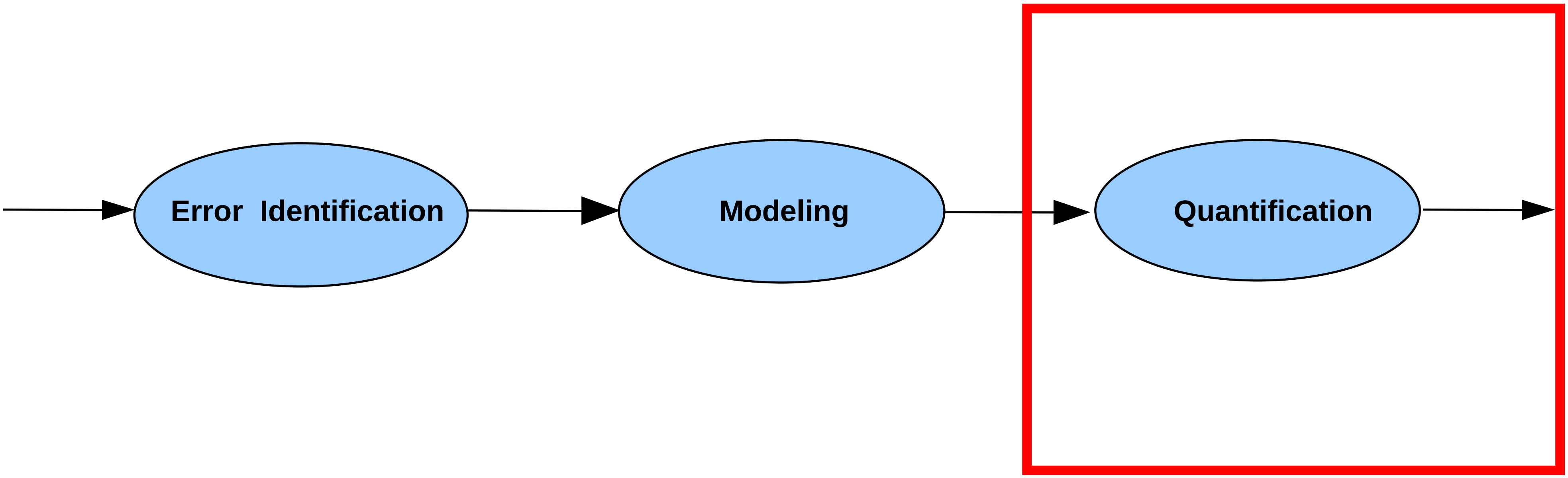
- Two notable approaches (EPRI SHARP1 and IEEE 1082) for integrating HRA into PRA are currently available
- These approaches elaborate on the error identification, modeling, and quantification areas addressed in this course
- HRA has a role to play during the entire PRA process

LESSON 5

HRA Quantification Phase



The essential HRA processes that are integrated into PRAs - HRA Quantification



Quantifying a Model

- Quantifying is the process of incorporating the right probabilities into a model
- The steps involved in the calculation depend on the method being used
- The data for the calculations may come from databases, simulations, expert judgment, and the HRA methods themselves
- The result is typically called a **Human Error Probability (HEP)**
- Various intermediate products may be created

Why Quantify HRA Models?

- Quantification is an essential part of PRA
- Quantification promotes prioritization of prevention/remediation activities (economic or safety analysis)
  - Evaluate alternative designs
  - Consider importance (risk contribution)
  - Lets you address magnitude of effects

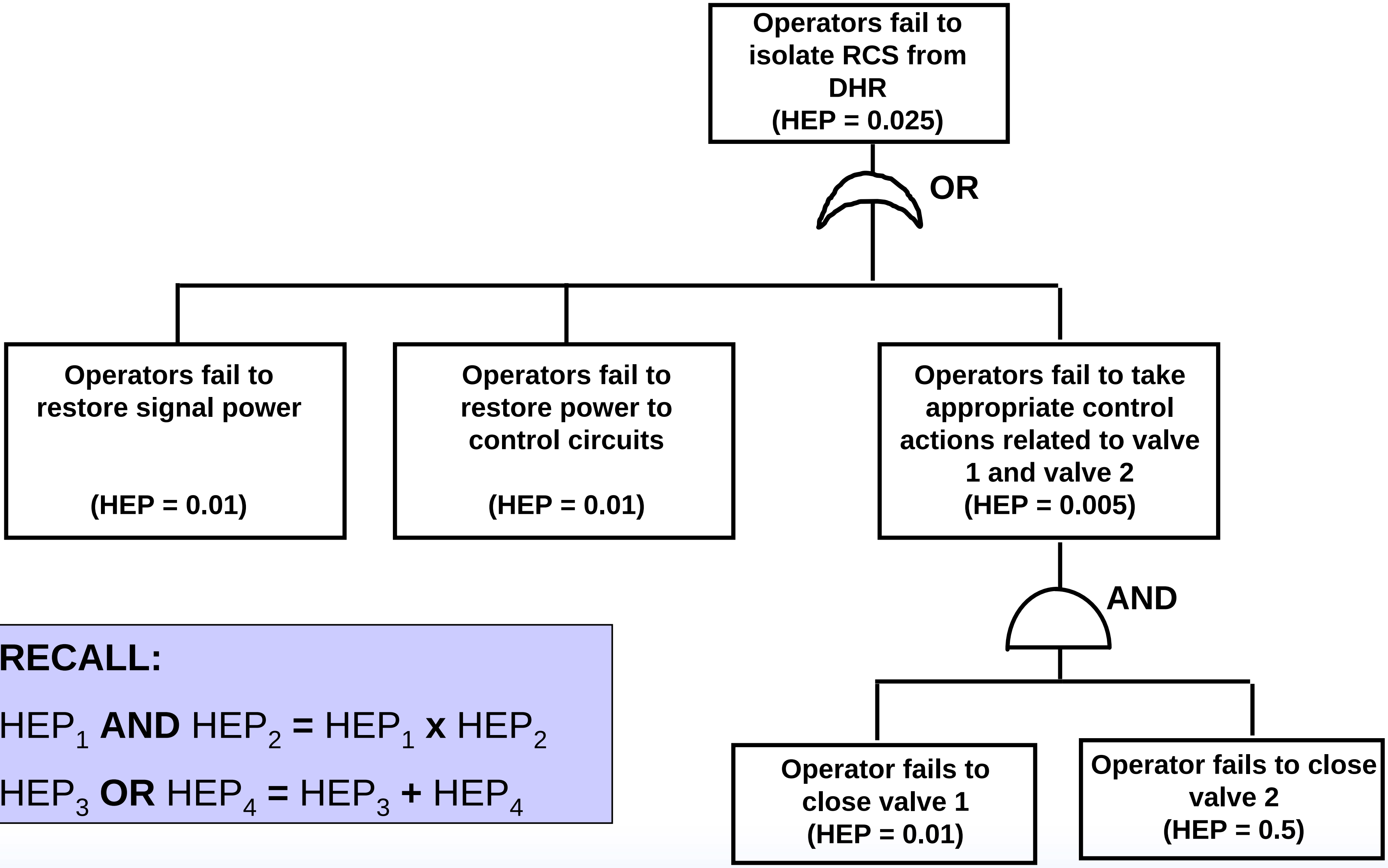
Two Levels of Precision

1. Conservative (**screening**) level useful for determining which human errors are the most significant detractors from overall system safety

   – An HEP for a modeled HFE may be set to a high value (e.g., 0.5) to determine if it is risk significant to the safety of the plant

2. Those found to be potentially significant contributors are analyzed in greater detail using more precise quantification

Sample HRA Quantification



RECALL:

HEP_1 **AND** HEP_2 **=** HEP_1 **x** HEP_2

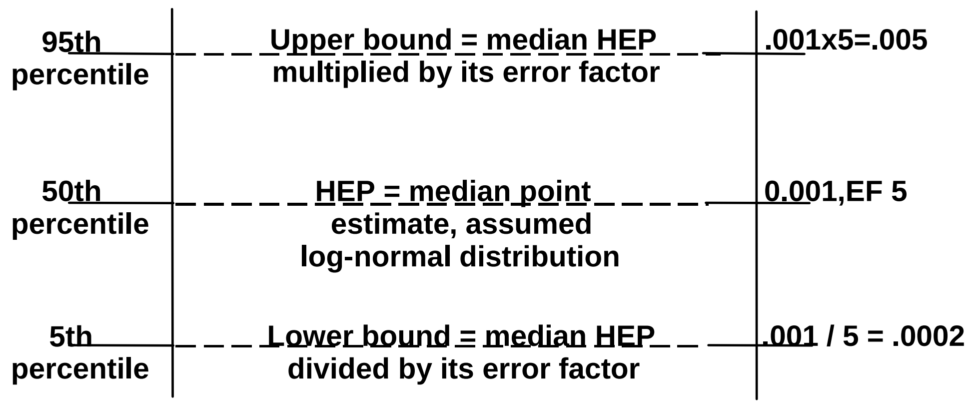
HEP_3 **OR** HEP_4 **=** HEP_3 **+** HEP_4

Median vs. Mean

Many of the techniques produce distributions described by a Median HEP and Error Factor (EF). These can be converted to Mean HEPs with uncertainty bounds for inclusion in PRAs

Quantification Concepts

- Base error rate
- Recovery, PSFs, and dependency modify base error rates
- Error factor (ratio of 95th/50th or 50th/5th)



Quantification Concepts (cont.)

HEP Range

- Average or nominal performance in the range of 1E-2 to 1E-3 (error 1/100 to 1/1000 times)
- Exceptionally good performance may be seen in the range of 1E-4 to 1E-5 (error 1/10,000 to 1/100,000 times)
- Poor performance may be seen in the range of 1.0 or 1E-1 (error all the time or 1/10 times)
- These values feature much lower reliability than is typical for hardware
  - Temptation in regulatory framework to want to drive HEP lower, but this is not realistic

Quantification Concepts (cont.)

Types of Quantification

- Holistic vs. atomistic approaches
  - *Holistic* looks at the whole task to arrive at an overall HEP
    - Common in expert elicitation approaches
    - E.g, HEART and THERP use a type of scenario matching that looks at overall similarity between analyzed task and predefined tasks
  - *Atomistic* looks at the drivers of the task to arrive at a computed HEP
    - Typically, PSFs serve as multipliers to compute the HEP
    - e.g., SPAR-H
- Note that THERP and HEART are actually somewhat hybrid approaches—they start with scenario matching but then modify that HEP on the basis of PSFs

Types of Quantification Techniques

- Simulation and Simulator
- Time Reliability Correlation
- Expert Estimation (Lesson 6)
- HRA Methods (Lesson 7)

Simulation and Simulator Techniques

Maintenance Personnel Performance Simulation (MAPPS)

- stochastic simulation, not widely used, mixed duration and accuracy for maintenance tasks

Cognitive Event Simulation (CES)

- developed at Westinghouse, sponsored by the NRC in the 1980s
- crews interact with a plant simulator and take actions linked to a simulation.

MicroSaint

- task analysis driven simulation
- very earliest origins were with Siegel and Wolf Model (SAINT) developed for the DoD
- Model enhanced and refined by MAAD
- basis of PHRED—NRC control room crew simulator using MicroSaint

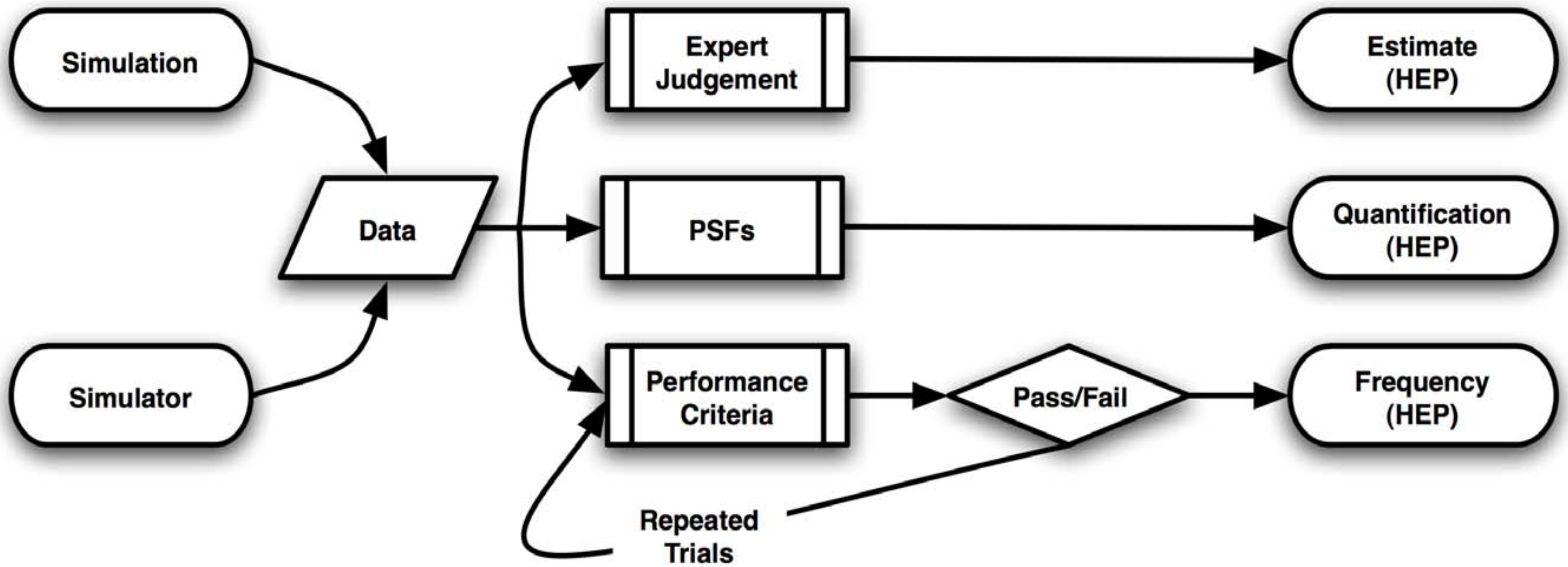
ADS/IDAC

- University of Maryland virtual plant and crew members

Many simulation techniques provide output in terms of time to complete tasks as opposed to HEPs

Use of Simulation and Simulators

- **Put the virtual back in reality!**
  - **Simulators:** real humans + virtual environments
  - **Simulation:** virtual humans + virtual environments
- **Human performance testing/determination of HEPs**



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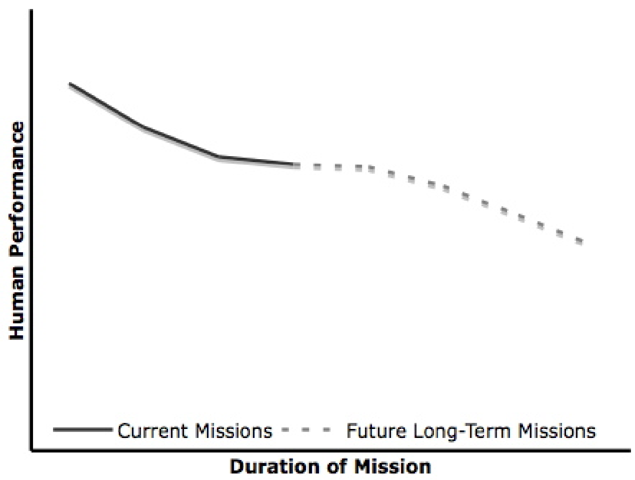
Simulation for Novel Domains in HRA

Quantification through Simulation

- Use of modeling and simulation system with virtual representation of humans to determine situations that may challenge human performance
- Process
  - System extensively calibrated to human performance in known situations
  - Across many Monte Carlo style trials, performance extrapolated to novel situation (e.g., long-duration space flight) for which actual human performance data have not been collected



  - Provides preliminary estimates of human error as well as “red flags” for situations that need to be further investigated to determine actual risk to humans or risk of human error

14

Time Reliability Techniques

Human Cognitive Reliability (HCR) and Operator Reliability Experiment (ORE) are two well-known efforts

- Human error rates are estimated as a function of time
- More time means less probability of error
- Often used to estimate the probability of decision type errors
- Not a discovery method for errors of commission
- Require accurate sequence, event, and performance time estimates
- Time Reliability Curve (TRC) estimates may be adjusted for additional influences (e.g., PSFs)

Calculation of Time Required and Time Available for Sequence RSD

	Time required		
RSD, EPF, BEFA, BEFF	*3 min.*	*or*	*180 sec.*
PFRO	*21 min.*	*or*	*1260 sec.*
CEM	*20.5 min.*	*or*	*1230 sec.*
VDP	*68 min.*	*or*	*4080 sec.*
LDWP	*84.5 min.*	*or*	*5070 sec.*
FIS	*. 5 min.*	*or*	*30 sec.*
TOTAL	*197.5 min.*	*or*	*11850 sec.*

Initiator to core damage (6 hrs) or	*21600 sec. TIME AVAILABLE*	Ratio is used most of the time
Sequence events -	*11850 sec. TIME REQUIRED*	
	9750 sec. (Time difference)	

How Can You Inform an Estimate?

- When using an HRA method or expert estimation for quantification, it is useful to anchor HEPs on actual human performance data
- NRC has developed various databases to capture human performance in nuclear power plant operations
- *Nuclear Computerized Library for Assessing Reactor Reliability* (**NUCLARR**; NUREG/CR-4639)
    - Captures HEPs from previous events and other data sources
    - No longer supported
- *Human Factors Information System* (**HFIS**; see CD)
    - Reviews all LERs for high-level human performance contributions
- *Human Event Repository and Analysis* (**HERA**) System (NUREG/CR-6903, Volumes 1 and 2; see CD)
    - Provides very detailed analysis of human performance in operating events and simulated events

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HFIS and HERA

Similarities

- Both are NRC-sponsored databases of human performance issues from reportable events at US nuclear power plants
- Both involve human reliability analysts reviewing event data and encoding according to a classification scheme

Differences

- HFIS
  - High-level human performance issues for trending
  - Production mode, whereby all suitable IRs and LERs are screened
- HERA
  - Detailed human performance analyses for informing error/risk estimation across HRA methods
  - Sampling of selective events, not production mode
  - Use of potentially diverse range of sources

HFIS and HERA serve complementary roles for capturing human performance data

LESSON 6

Expert Estimation

Exercise: Expert Estimation

- Estimate how many beans there are
- Report your estimate and discuss

Some Expert Estimation Techniques

- Nominal Group Technique (NGT)
- Delphi Technique
- Success Likelihood Index Method (SLIM)
- Meyer and Booker Compendium (NUREG/CR-5424; see CD)
- ATHEANA (NUREG-1880; see CD)
- ASP Program Simplified Expert Elicitation Guideline (see CD)

Issues with Expert Estimation

- Subject matter experts may not be experts at producing probabilities
  - Generally, humans are not skilled at translating mental representations into quantities
- Quality of information presented to the expert can greatly affect estimate
- Experts often do not agree
  - In a group setting, one expert may dominate or influence others
  - In a group setting, it may be difficult to reach consensus
  - Experts may not be calibrated to the same numeric scale—even if they actually agree, they may not generate the same result

Improving Expert Elicitation

- Need to recognize that knowledge is gained from reason, intuition, experiences
  - Harness multiple, qualified experts
- Provide sufficient background and issue familiarization to appropriate level of detail
- Reproducibility important
  - Document all assumptions and processes
- Emphasize accountability
  - Experts should be willing to "sign off" on estimates
- Provide training and calibration of experts to the extent possible
- Try to avoid exaggerated illusion of precision
  - An expert-generated HEP should not be a substitute for empirically derived data
- Estimation should be an iterative process
  - Have experts review and revise results

Calibrating Experts

Possible Calibration Points (from ATHEANA User's Guide, NUREG-1880)

Circumstance	Probability	Meaning
The operator(s) is "Certain" to fail	1.0	Failure is ensured. All crews/operators would not perform the desired action correctly and on time.
The operator(s) is "Likely" to fail	~0.5	5 out of 10 would fail. The level of difficulty is sufficiently high that we should see many failures if all the crews/operators were to experience this scenario.
The operator(s) would "Infrequently" fail	~0.1	1 out of 10 would fail. The level of difficulty is moderately high, such that we should see an occasional failure if all of the crews/operators were to experience this scenario.
The operator(s) is "Unlikely" to fail	~0.01	1 out of 100 would fail. The level of difficulty is quite low and we should not see any failures if all the crews/operators were to experience this scenario.
The operator(s) is "Extremely Unlikely" to fail	~0.001	1 out of 1000 would fail. This desired action is so easy that it is almost inconceivable that any crew/operator would fail to perform the desired action correctly and on time.

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Exercise: Expert Estimation

Use the ATHEANA anchor values to estimate these likelihoods:

- You take a wrong turn while driving to work
- You run a red light while turning left at an intersection
- You get off at the wrong metro stop on the way to class
- You miss an important text message from a friend because you are so engrossed in the instructor's lecture
- You forget to send an attachment with an email to your manager

What factors weighed into your decision?

Example: NRC Expert Estimation Guideline

Expert elicitation is needed for cases when:

- There are infrequent events that are not included in PRA or HRA models
- There is inadequate operational or experimental data to arrive at probabilistic estimates

Expert elicitation methods may be:

- Costly
- Time-consuming
- Not always tractable

Need an expert elicitation approach that is:

- Cost effective
- Quick to meet Significance Determination Process (SDP) and Accident Sequence Precursor (ASP) deadlines
- Scrutable

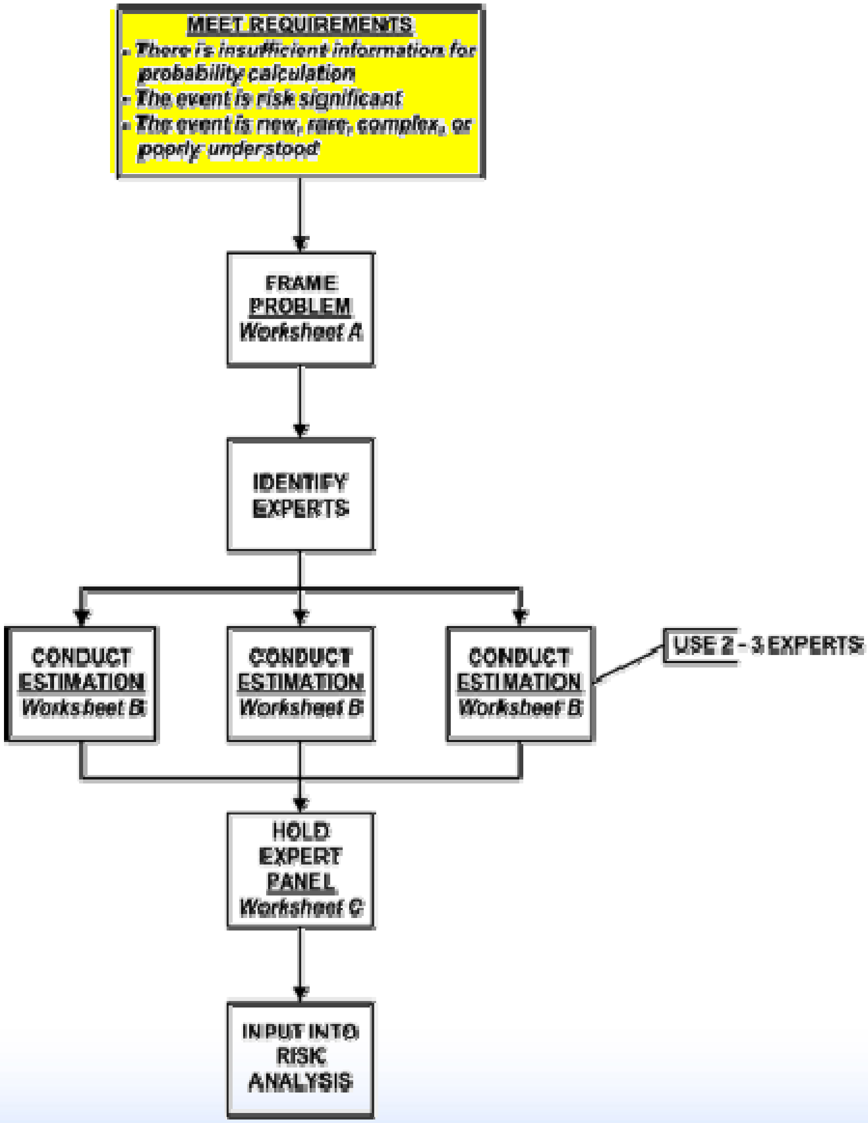
Guideline Overview

Worksheet Based Approach for Hardware (PRA) or Human (HRA) Events (see CD)

- Background Information/Problem Framing
- Individual Expert Elicitation
- Aggregation
  - Consensus
  - Panel
  - Mathematical
- Checklist

	Hardware Failure	Human Error
Problem Framing	Appendix A	Appendix A
Expert Elicitation	Appendix B	SPAR-H Worksheets
Estimate Aggregation	Appendix C	Appendix D
Elicitation Checklist	Appendix E	Appendix E

Expert Estimation for Hardware



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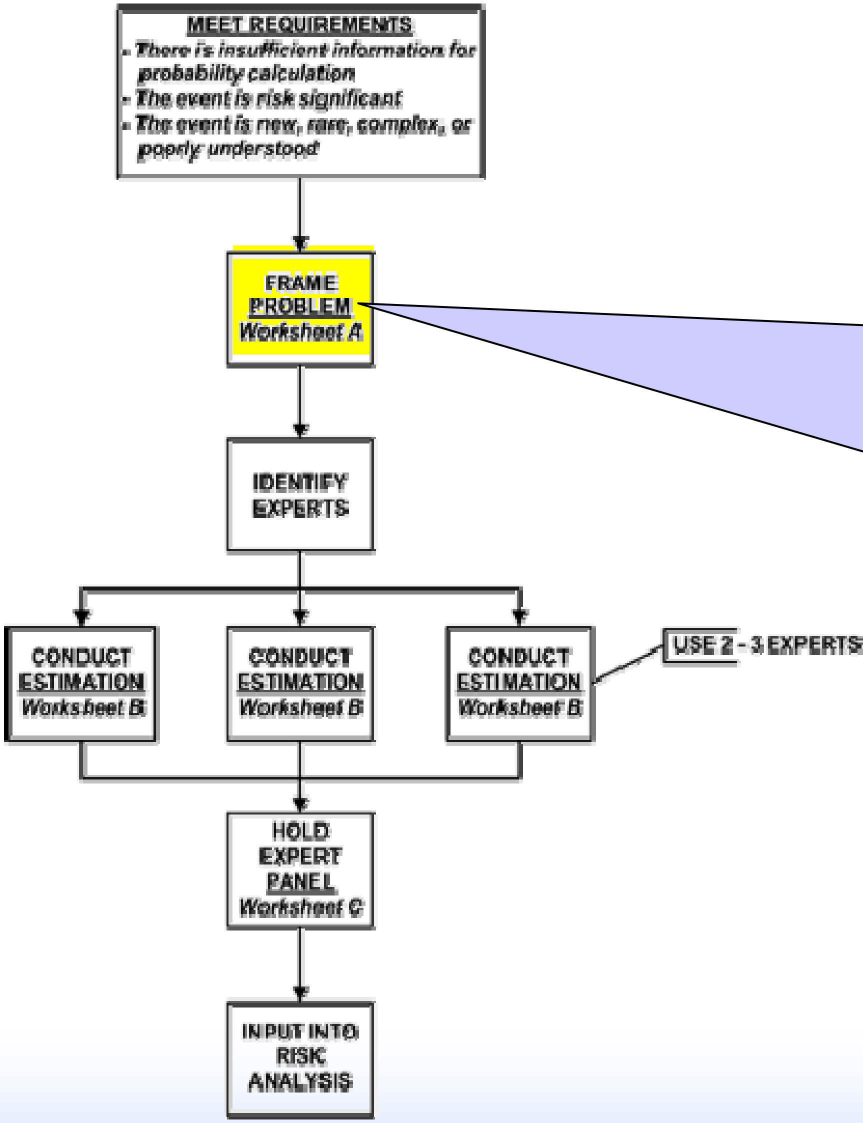
Expert Estimation for Hardware



Key Steps

- Determine Problem
- Summarize Problem
- Provide Background Materials
- Provide Any Initial Results
- Define Assumptions
- Define What is Sought from Experts

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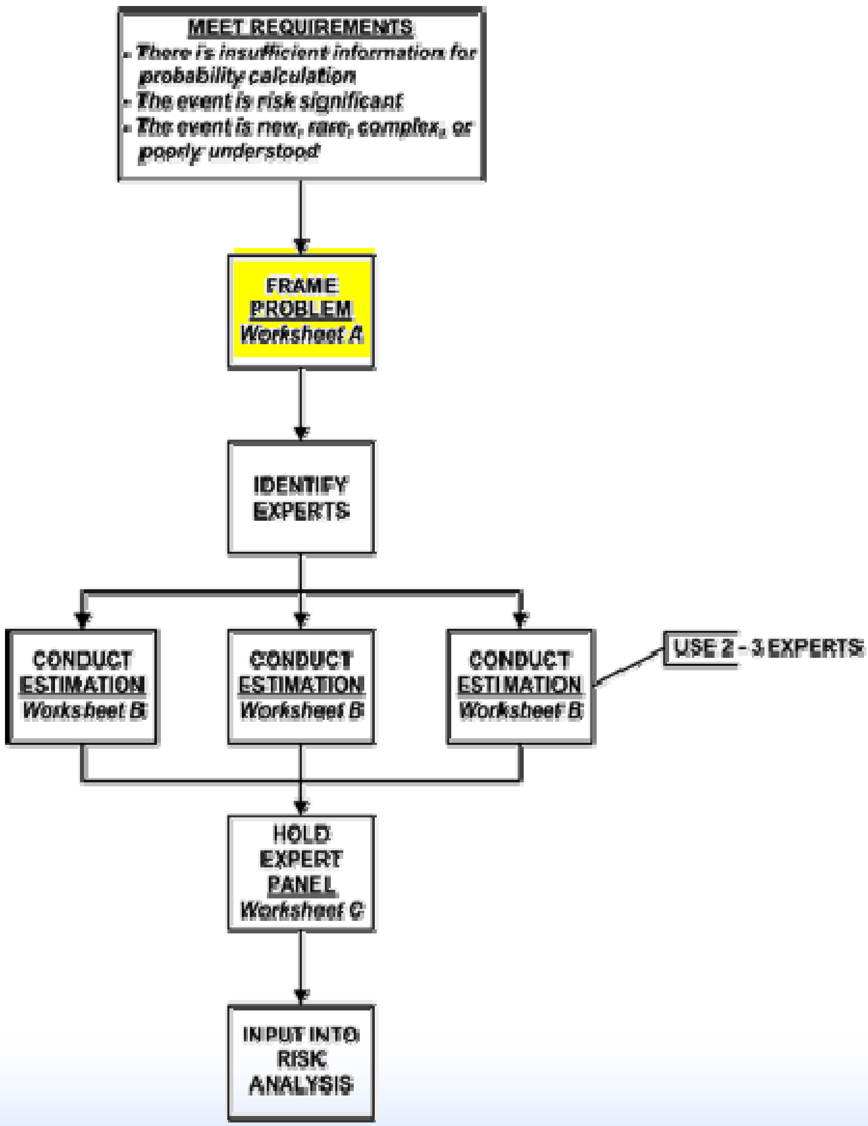
Expert Estimation for Hardware



APPENDIX A

EXPERT ELICITATION BACKGROUND INFORMATION WORKSHEET

Instructions. Complete this worksheet prior to contacting the expert. Provide this worksheet and supporting materials to present the problem domain to the expert. All experts should receive identical information.

1. Analyst's Name and NRC Affiliation: ______________________

2. Problem Type: ☐ Actual Hardware Failure ☐ Latent Hardware Failure ☐ Other: ________ ☐ Actual Human Error ☐ Latent Human Error

3. Summary of Problem for Analysis: ______________________

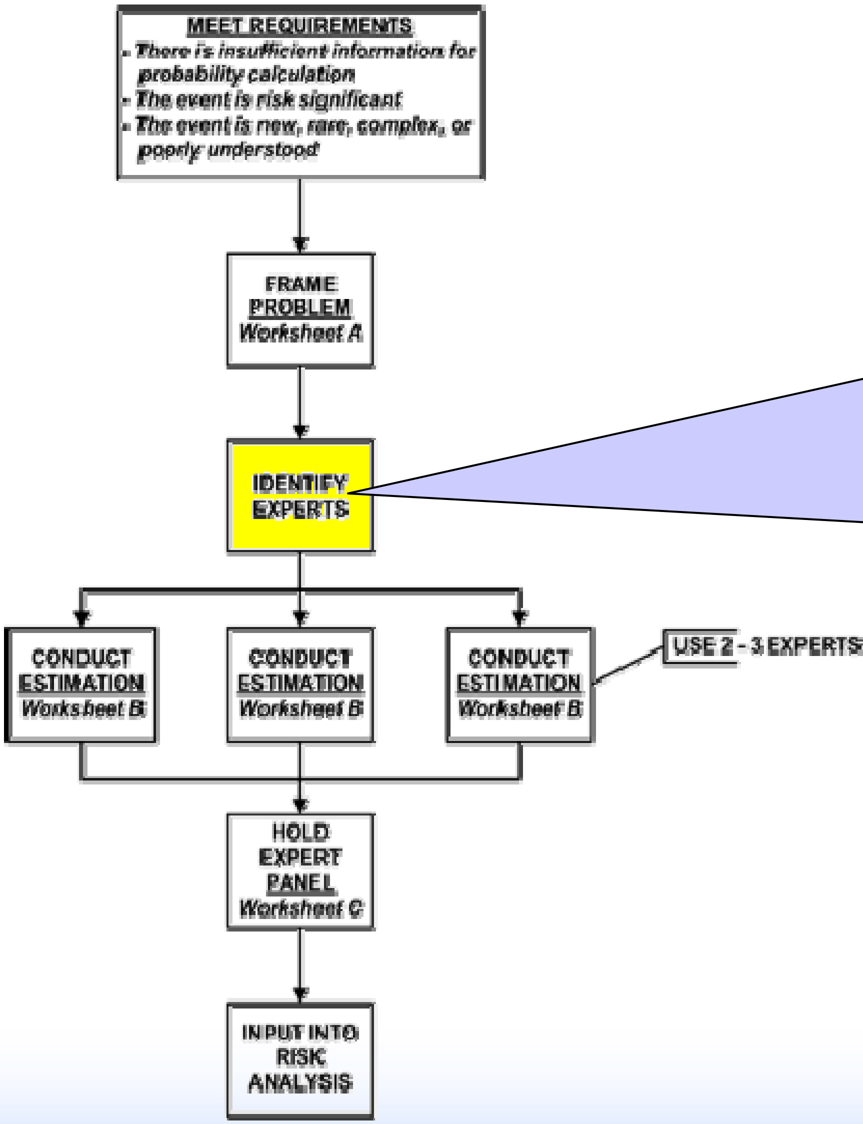
4. Supporting Documents (Attached): ______________________

5. Summary of Results from Initial Analysis: ______________________

6. Analysis Assumptions: ______________________

7. Information Required from Expert: ______________________

Expert Estimation for Hardware



Multiple Experts

- Attenuates the Effect of Any Single Expert's Bias
- Use 2-3 experts, except where CCDF > 1E-4
- For CCDF > 1E-4, use full-scale expert elicitation such as Meyer & Booker's NUREG/CR-5424

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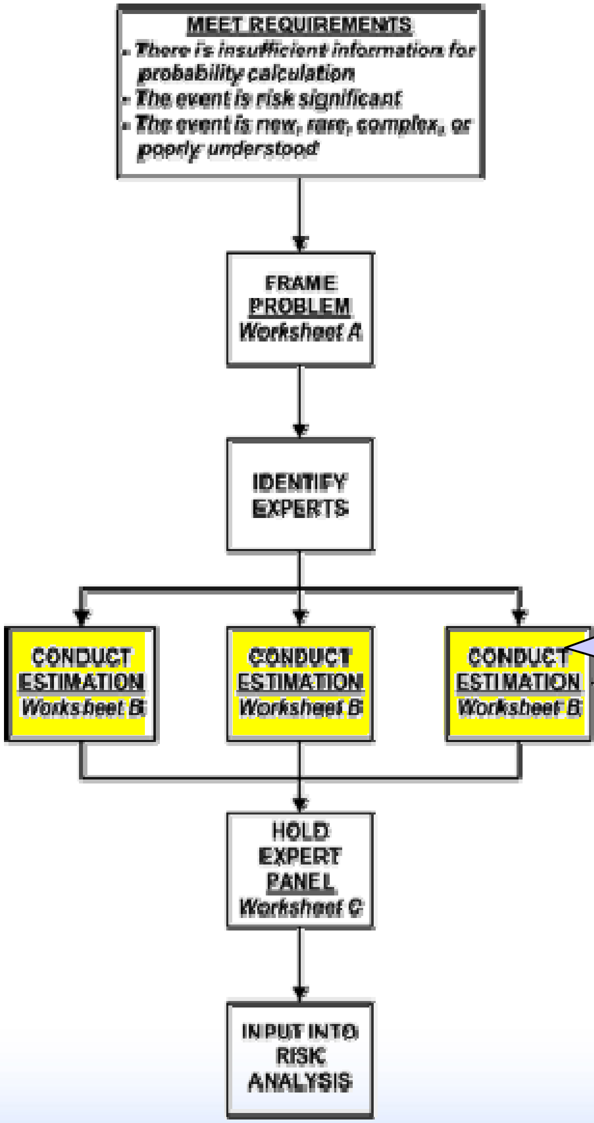
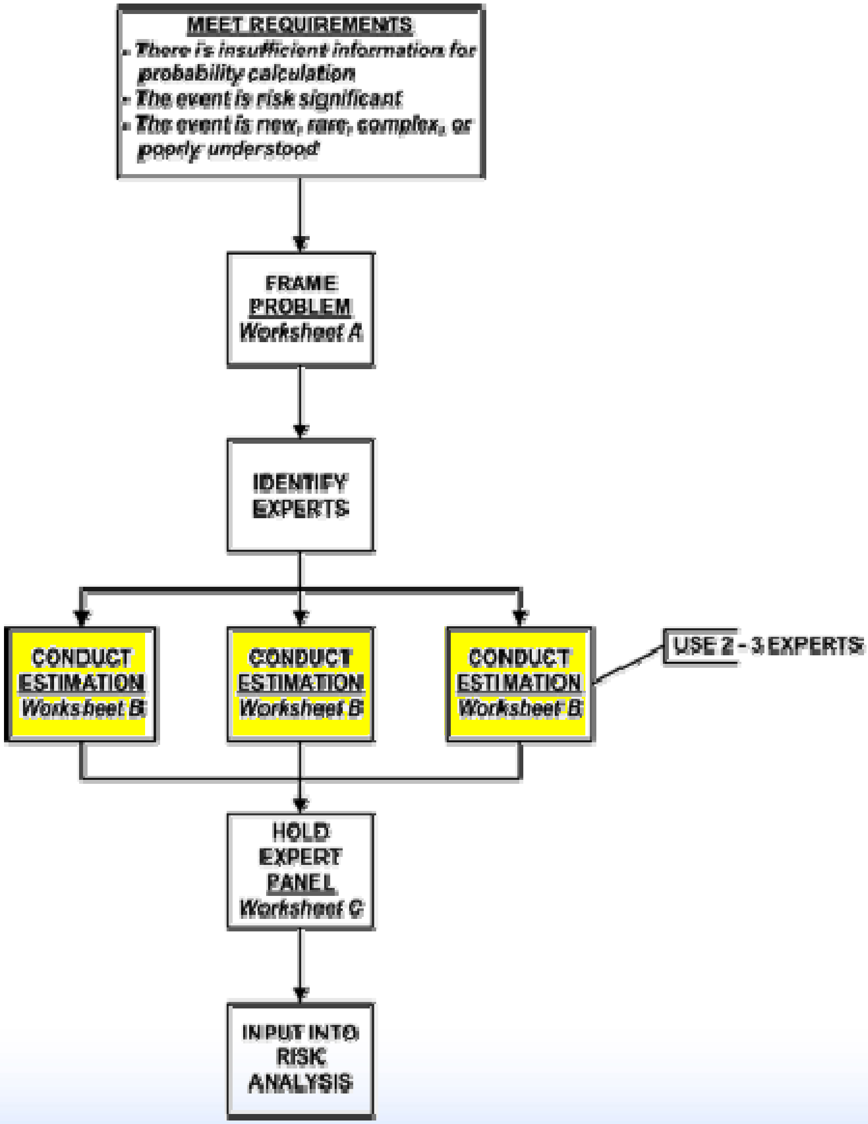
Expert Estimation for Hardware



<u>Conduct Estimation</u>

- Expert Provides Credentials/ Expertise
- Expert Recounts Problem
- Expert States Assumptions
- Expert provides "worst case" ('point at which the system will almost certainly fail' = upper bound = 95%tile)
- Expert provides "typical case" ('point at which the system will fail half of the time' = median = 50%tile)

Expert Estimation for Hardware



APPENDIX B

EXPERT ELICITATION WORKSHEET FOR HARDWARE FAILURE

Instructions. Complete this worksheet for each individual expert. Begin by answering any questions the expert has regarding the problem being analyzed. Then step through each question in sequence. Attach any supporting materials provided by the expert.

1a. Date of Elicitation: ___ / ___ / ______ 1b. Time of Elicitation: ___ : ___ ☐ A.M. / ☐ P.M.

2. Expert's Name and Affiliation: ______________________________

☐ In-house NRC ☐ Industry Consultant ☐ Academia ☐ Other:
☐ National Lab/DOE ☐ Licensee ☐ Vendor ______________

3. Expert's Areas of Expertise Relevant to Analysis: ______________________________

4. Expert's Comments on Problem Under Analysis: ______________________________

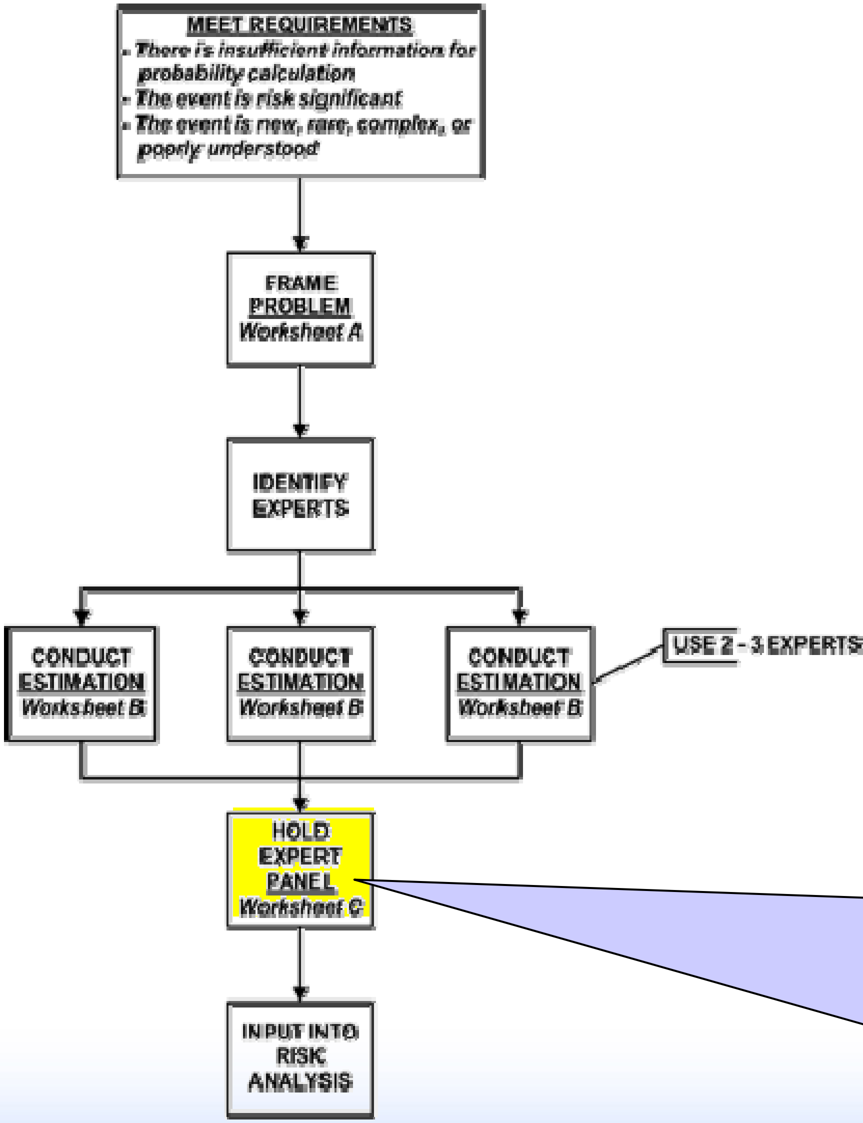
5. Median Failure Rate/ Percent of Time There's a 50/50 Likelihood of Hardware Failure: ________ 50th Percentile Value (Median)

6. Upper Bound/Percent of Time That Hardware Will Almost Certainly Fail: ________ 95th Percentile Value (Upper Bound)

7. Factors Shaping Expert Estimate: ______________________________

8. Additional Comments by Expert: ______________________________

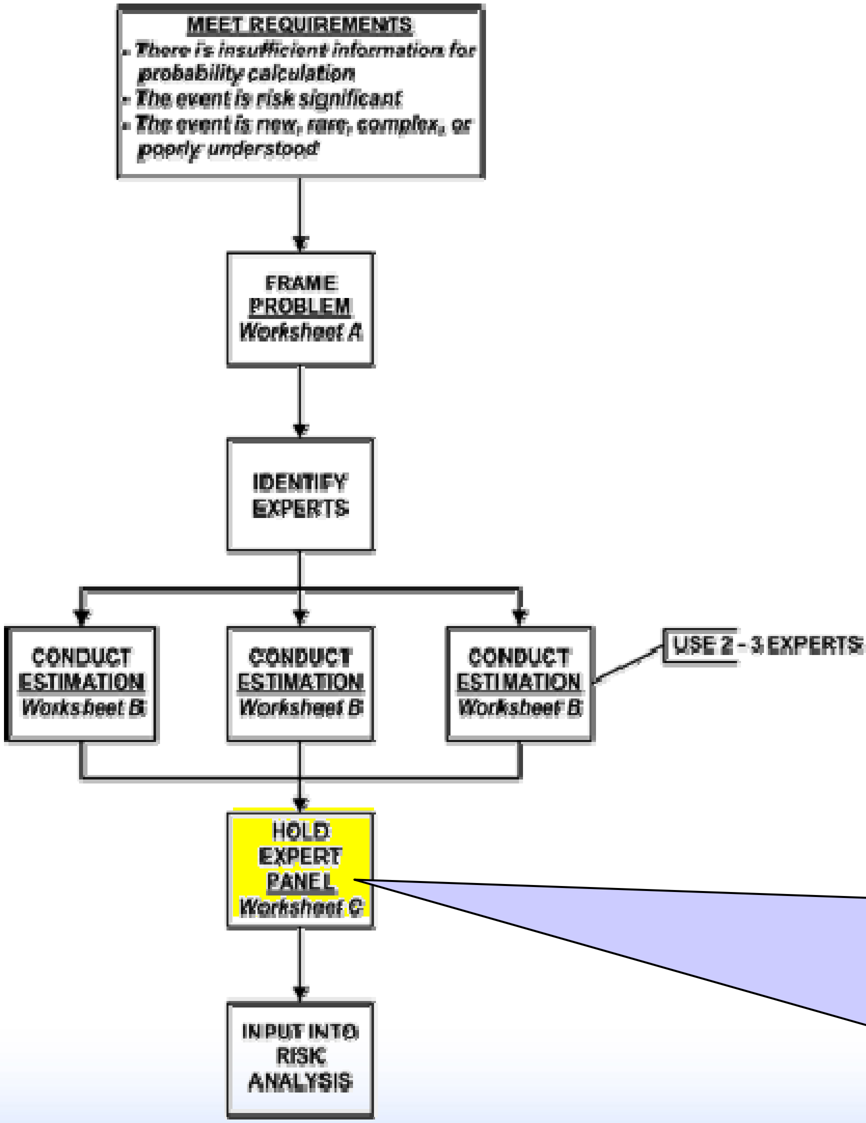
Expert Estimation for Hardware



Sample Panel

Analyst:	Introduction to topic and experts *(5 mins.)*
Analyst:	Summary of each expert's estimation *(5 mins. per expert)*
Experts:	Questions and discussion to clarify estimations *(5 – 10 mins.)*
Experts:	Discussion of issues *(10 – 15 mins.)*
Experts:	Consensus discussion *(10 – 15 mins.)*
Analyst:	Summary of issues and resolution *(5 mins.)*

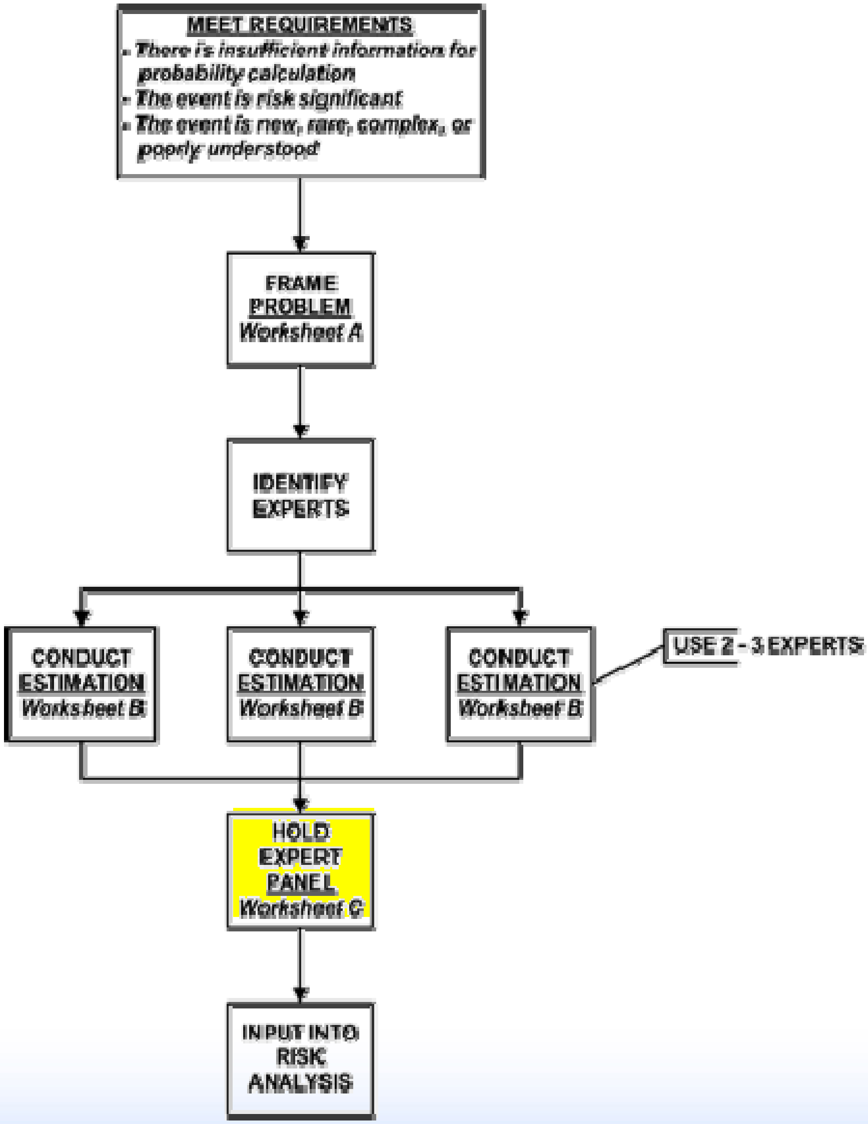
Expert Estimation for Hardware



Sample Panel Outcomes

- The panel reaches "consensus" and agree on the estimates
- The panel does not reach consensus, and it is necessary to mathematically aggregate the estimates

Expert Estimation for Hardware



APPENDIX C

EXPERT ELICITATION PANEL WORKSHEET FOR HARDWARE FAILURE

Instructions. Complete this worksheet for the expert panel and data aggregation. Follow instructions in the guideline for facilitating the discussion. Begin by explaining the purpose of the panel, with a goal toward sharing information and arriving at a consensus. Next, read each expert's estimation. Provide the initial aggregation of expert estimates in 3 below. Allow 5 - 10 minutes for questions and another 10 - 15 minutes for discussion. Allow 5 minutes for final discussion and consensus. Allow the experts to modify their individual Worksheet B to incorporate any new information from the discussion.

1a. Panel Conducted? ☐ Yes / ☐ No 1b. Reason: ____________________

____

1c. If NO, Skip to 5

2a. Date of Panel: ___ / ___ / _____ 2b. Time of Panel: ___ : ___ ☐ A.M. / ☐ P.M.

3. Mean of Experts' Median __________ and 95th Percentile __________ Values

4. Summary of Main Points and Issues Raised in Discussion (Including Areas of Disagreement):______

____

____

____

____

____

____

____

____

____

5. Consensus Estimate (Within 3x for Median)? ☐ Yes / ☐ No

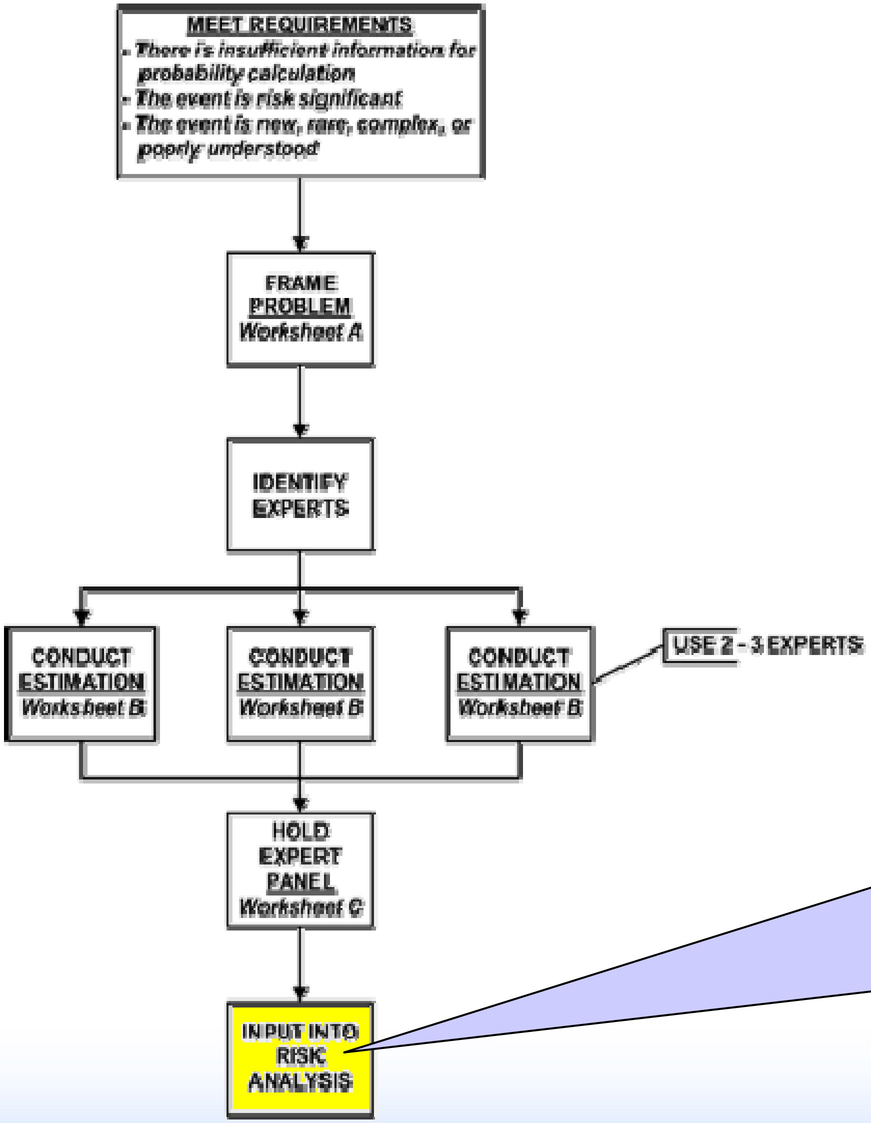
6a. If YES, Record Median of Median __________ and 95th Percentile __________ Values

6b. If NO, Record Mean of Median Estimates __________ and 95th Percentile Values__________

7. Record Alpha (α) __________ and Beta (β) __________ Values Derived from 6a or 6b for Beta Distribution or Other Parameters for Non-Beta Distribution:____________________

____

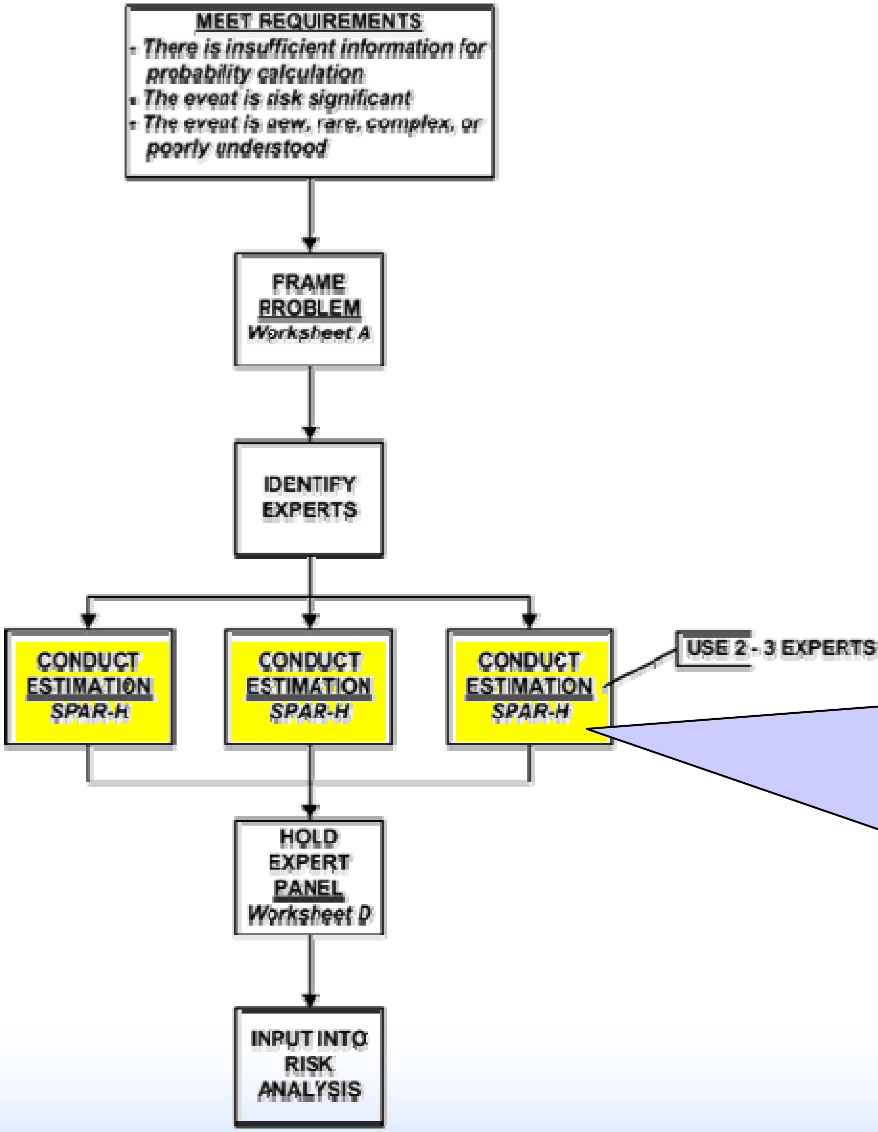
Expert Estimation for Hardware



Input into PRA

- Expert Elicitation Guideline Provides a Simple Excel Solver to Convert Median and Upper Bound Values into Alpha and Beta Required for Beta Distribution

Expert Estimation for Human Error



SPAR-H Estimations

- NRC's ASP Group has Determined that SPAR-H Method is to be Used for HRA Estimates. Worksheets Provided for Recording Estimates and Aggregating Them. If SPAR-H is Not Appropriate, Approach Can be Adapted to HRA without SPAR-H.

Validation

Methodological Validation

- Method derived from interviews with 20 ASP and SDP analysts
- Three iterations of guideline with NRC peer review

Implementational Validation

- PRA case study on incident involving air in HPSI pumps at Palo Verde Nuclear Power Plant
  - Two pump experts reached consensus on estimate
- HRA case study on SGTR incident at Indian Point 2 Plant
  - Two human factors experts completed SPAR-H worksheets
  - Guideline provided novel approach to aggregating estimates

Regulatory Uses of Guideline

Goals Met

- Support probabilistic estimation for hardware and human events for which current models do not provide sufficient detail and for which expert estimation is needed
- Provide scrutable, usable, and streamlined basis for expert estimation in SDP and ASP analyses
  - **Scrutable:** Full documentation through worksheets
  - **Usable:** Analysts able to complete with minimal training; experts able to complete probabilistic estimation using information provided in worksheet
  - **Streamlined:** Full elicitation took a few hours, not days or weeks

LESSON 7

HRA Methods Overview

A Snapshot of NRC HRA Methods

- Technique for Human Error Rate Prediction (THERP)
- Accident Sequence Evaluation Program (ASEP)
- Simplified Plant Analysis Risk-Human Reliability Analysis (SPAR-H) Method
- A Technique for Human Event Analysis (ATHEANA)

THERP (NUREG-CR/1278)

- Developed by Alan Swain, et al., at Sandia National Laboratories for US NRC in early 1980s
  - Precursors to THERP go back to the 1950s
  - Parts of what became THERP appeared in WASH-1400
- Based on data gathered from reactor control room, bomb-building, and chemical processing activities, as well as expert estimation
- Historically most widely used method
- Validates as well or better than any other technique

THERP (Continued)

- Uses HRA event tree modeling
- Applies data and modifications from tables (see THERP Chapter 20; included here in **Appendix C**) for quantification
- Often misapplied (quantify top level without modeling and quantifying subtasks)

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How THERP Works

1. For a given subtask, find the most appropriate lookup table

2. Within the selected lookup table, choose the best fitting **Nominal HEP** and error factor

3. Modify this value as needed to account for stress, task type, level of experience/training. (Multiply by 1, 2, 4, 5, or 10—see Table 20-16); yields a **Basic HEP**

4. Modify this value for dependence, as needed (see Table 20-17); the resulting HEP is called a **Conditional HEP**

How THERP Works (Continued)

5. Calculate values of each failure path.

6. Sum up all failure paths to obtain total task failure.

7. Run sensitivity analysis by making reasonable changes to Nominal, Basic, or Conditional HEPs or by changing model (adding or removing failures and/or recoveries)

Navigating THERP Tables

- Figure 20-2 from THERP sorts tables out by their function
  - Screening
  - Diagnosis
  - Errors of Omission
  - Errors of Commission
  - PSFs
  - Uncertainty Bounds
  - Recovery Factors

Navigating THERP Tables (Continued)

- Figure 20 -1 of THERP Handbook provides overall logic for using THERP and tables
- Pages 20 -11 through 20 -13 of THERP Handbook list all 27 THERP Tables
- Given an HRA Event Tree, to quantify a branch, find the correct table and item

THERP Dependency

THERP Definitions:

- **Dependency** is “Determination of how the probability of failure or success on one task may be related to the failure or success on some other task”
- “Two events are ***independent*** if the conditional probability of one event is the same whether or not the other event has occurred. That is, independence is the case in which the probability of success or failure on Task ‘B’ is the same regardless of success or failure on Task ‘A’”
- “If events are not independent, they are ***dependent***”

THERP Dependency (Continued)

Two types of dependency in THERP

- ***Direct dependence*** exists when the outcome of one task directly affects the outcome of a second task
  - Failure on Task “A” causes an auditory signal that results in more careful performance on Task “B”
  - Failure on Task “A” causes extreme anxiety with a resultant increase in probability of failure on Task “B”
  - Failure on Task “A” causes Task “B” to be more difficult with an associated increase in probability of failure

THERP Dependency (Continued)

Two types of dependency in THERP (continued)

- ***Indirect dependence*** occurs when some PSF or set of PSFs influences the relationship between tasks such that the dependence between them changes
  - If the PSF merely raises or lowers the HEPs for tasks without changing the relationship between them, this is not an example of indirect dependence
    - A high level of stress tends to increase HEPs across tasks but not necessarily change dependence
    - Stress leads to dependency *only* if it also causes a systematic change in behavior across events (e.g., if stressed operators defer decisions to shift supervisor--something they would not do in an unstressed state)

THERP (NUREG/CR-1278) Dependency

THERP covers five levels of dependency, from zero dependence (ZD) to complete dependence (CD)

- Covered for success and failure paths
- ***Success path*** = dependency between two events with successful outcomes
- ***Failure path*** = dependency between two events with unsuccessful outcomes (human error)

Level of Dependence	Success Equations	Equation No.	Failure Equations	Equation No.
ZD	$Pr[S_{"N"}\|S_{"N-1"}\|ZD] = n$	(10-9)	$Pr[F_{"N"}\|F_{"N-1"}\|ZD] = N$	(10-14)
LD	$Pr[S_{"N"}\|S_{"N-1"}\|LD] = \frac{1 + 19n}{20}$	(10-10)	$Pr[F_{"N"}\|F_{"N-1"}\|LD] = \frac{1 + 19N}{20}$	(10-15)
MD	$Pr[S_{"N"}\|S_{"N-1"}\|MD] = \frac{1 + 6n}{7}$	(10-11)	$Pr[F_{"N"}\|F_{"N-1"}\|MD] = \frac{1 + 6N}{7}$	(10-16)
HD	$Pr[S_{"N"}\|S_{"N-1"}\|HD] = \frac{1 + n}{2}$	(10-12)	$Pr[F_{"N"}\|F_{"N-1"}\|HD] = \frac{1 + N}{2}$	(10-17)
CD	$Pr[S_{"N"}\|S_{"N-1"}\|CD] = 1.0$	(10-13)	$Pr[F_{"N"}\|F_{"N-1"}\|CD] = 1.0$	(10-18)

Exercise: THERP Quantification

- See Appendix D

ASEP (NUREG-CR/4772), Briefly Noted

- Developed by Swain as an easy-to-use simplification of THERP
- Provides separate guidance and quantification for pre- and post-accident tasks
- Distinguishes between screening values and nominal values (those values that are quantified at a more explicit level than the screening values)
- Provides simplified tables according to pre/post accident phase and screening/nominal analysis, with resulting HEP and Error Factors
- Recovery and dependency modeling similar to THERP

SPAR-H (NUREG/CR-6883)

The SPAR HRA, or SPAR-H, method was developed to
support NRC's ASP program

- The current Standardized Plant Analysis Risk (SPAR) models evolved from the early ASP PRAs
- Now exist in full-power models for each plant
- Being applied to low power and shut down models

SPAR-H is used as a simplified HRA approach

- Like ASEP, SPAR-H is a simplified approach based on THERP
  - HEPs in SPAR-H derived from THERP
  - Approach uses PSFs instead of sample scenarios, making it easier to generalize

SPAR-H Quantification

- SPAR-H Worksheets are used to quantify HEPs by considering factors that may increase/decrease likelihood of error
  - Available time
  - Complexity
  - Procedures
  - Fitness for duty

  - I
  - I
  - V

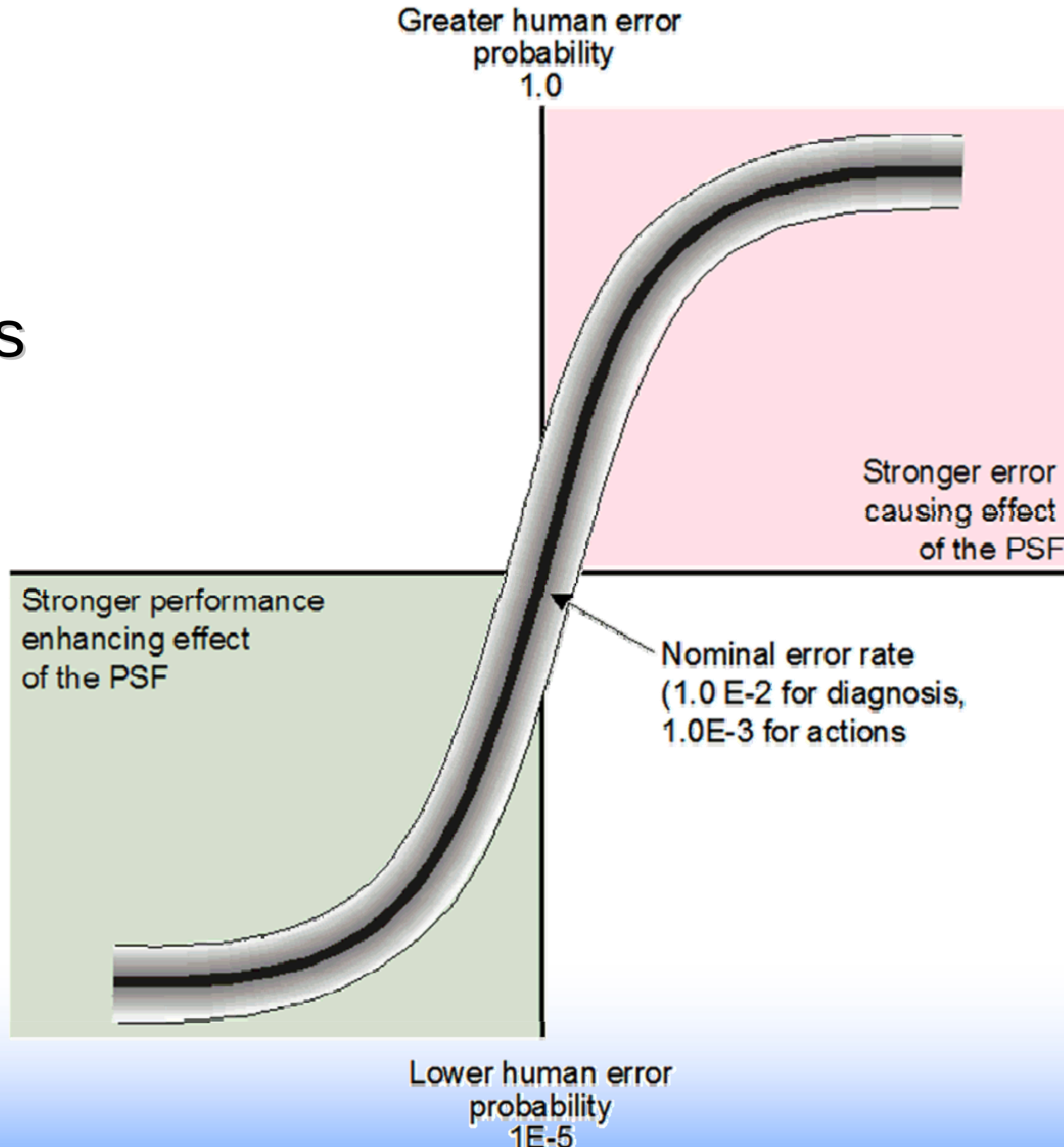
<u>Example: Available Time</u>

- ***inadequate time*** **→ *p(failure)* = 1.0**
- ***barely adequate time*** **→ *p(failure)* = HEP x 10**
- ***nominal time*** **→ *p(failure)* = HEP x 1**
- ***extra time*** **→ *p(failure)* = HEP x 0.1**
- ***expansive time*** **→ *p(failure)* = HEP x 0.01**

- In the SPAR-H method, these influences are specifically called PSFs

SPAR-H Shown Graphically

- PSFs influence performance, which determines likelihood of human error probability



SPAR-H Worksheet Types

- The current SPAR-H method has separate worksheets (see **Appendix E**) for:
  - Diagnosis-type activities (e.g., determining whether to start a pump or not)
  - Action-type activities (e.g., restoring a pump after it fails, performing a valve line-up)
- Different modes of power operation are included
  - At power operations
  - Low power and shutdown operations

SPAR-H Worksheet Process

- What an example SPAR-H worksheet looks like
- In general, filling out the worksheet follows

Step 1 – Task error ID and question diagnosis

Step 2 – If diagnosis is applicable, complete Table 1

Step 3 – If action is applicable, complete Table 2

Step 4 – Estimate HEP via Table 3

Step 5 – Adjust HEP for dependencies

SPAR Model Human Error Worksheet (Page 2 of 3)

Table 2. Action worksheet.

PSFs	PSF Levels	Multiplier for Action	If non-nominal PSF levels are selected, please note specific reasons in this column
1. Available Time	Inadequate	1.0[a]	It is assumed that the operators have just enough time to recover the SWS.
	Time available ≈ time required	10✓	
	Nominal	1	
	Available >50x time required	0.01	
2. Stress	Extreme	5	It is assumed that the stress level is greater than nominal.
	High	2✓	
	Nominal	1	
3. Complexity	Highly	5✓	It is assumed that the complexity is greater than nominal.
	Moderately	2	
	Nominal	1	
4. Experience/ Training	Low	3	
	Nominal	1✓	
	High	0.5	
5. Procedures	Not available	50	
	Available, but poor	5	
	Nominal	1✓	
6. Ergonomics	Missing/Misleading	50	
	Poor	10	
	Nominal	1✓	
	Good	0.5	
7. Fitness for Duty	Unfit	1.0[a]	
	Degraded Fitness	5	
	Nominal	1✓	
8. Work Processes	Poor	2	
	Nominal	1✓	
	Good	0.8	

SPAR-H Worksheet Process (cont.)

Step 4, estimate the HEP:

1. Begin with a "nominal" HEP value

   ➲ 1E-2 for diagnosis ➲ 1E-3 for action

2. Multiply nominal HEP by the applicable PSF "factor"
   - For example, if the context related to complexity is "highly complex," PSF factor has a value of 5
   - Most factors are greater than one, but some are less than one (this allows for consideration of the positive influence of PSFs which may be present)
3. Repeat step 2 for each PSF

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SPAR-H Worksheet Process (cont.)

The SPAR-H worksheet allows for efficient estimation of an HEP

- HEP value is assumed to be a mean value

SPAR-H method advocates a “constrained noninformative prior” uncertainty distribution

- This distribution preserves the mean value while expressing relevant uncertainty as a beta distribution

An adjustment factor is provided for instances where multiple, negative PSFs are present

Lastly, dependency between events is considered

- Operator failure on first action implies that subsequent actions may have a higher-than-normal failure probability
- The subsequent SPAR-H HEPs are adjusted upwards in this case

SPAR-H Dependency Table

If tasks are dependent, apply the following table:

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?________________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. If this error is the **4th error in the sequence**, then the dependency is at least **high.**
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	

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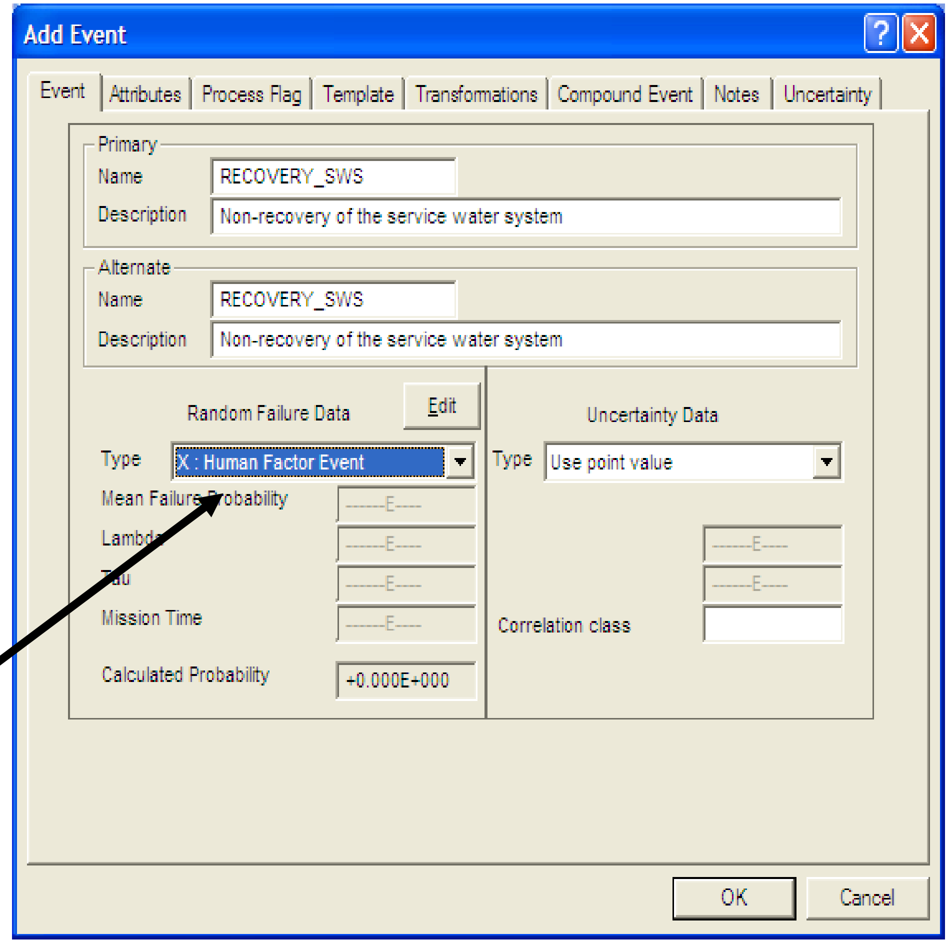
The SPAR-H Calculator

- Current versions of the NRC SAPHIRE risk/reliability software contain a SPAR-H calculator
  – Human error probability events are modeled in a PRA as “basic events”
  – These basic events utilize the SPAR-H calculator to determine their probability
- Like the SPAR-H worksheets, the HEP is based on whether the task requires diagnosis or an action
- The Calculator is discussed in a separate SAPHIRE course, but we will describe the process here

The SPAR-H Calculator (cont.)

- In a PRA, operator actions appear as basic events
- In SAPHIRE, one would create a basic event
  - For example, via the "Modify → Basic Event" option
  - Then, give the event a name and description
    - We are going to use non-recovery of service water as our example
  - Further, we tell SAPHIRE this is a "human factor event"

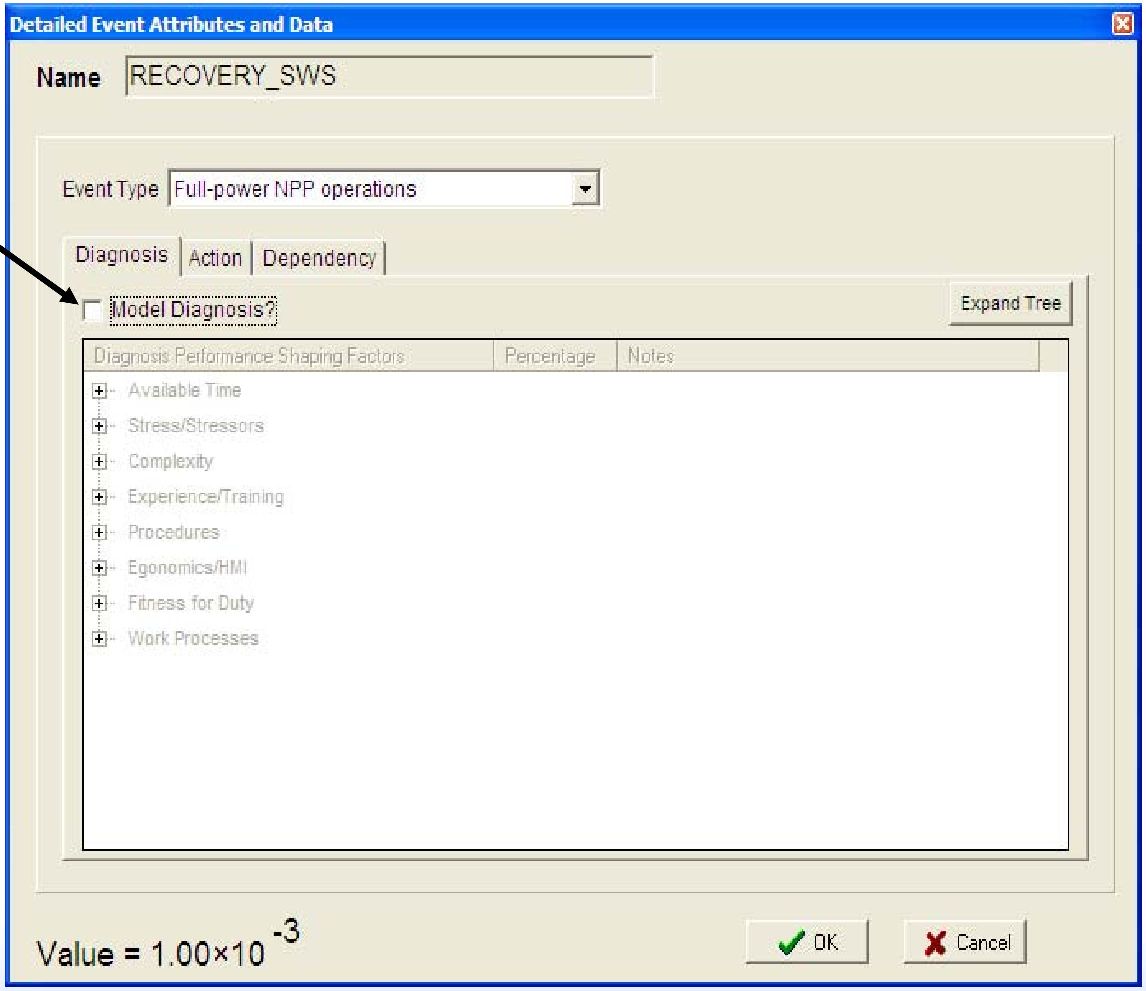


The SPAR-H Calculator (cont.)

- Next, we edit the SPAR-H Calculator parameters
  - The parameters are the SPAR-H PSFs
- The first tab (see next page) allows the diagnosis portion of the event to be modified
  - This screen is used only if diagnosis is an important activity
  - In recovery of service water, we assume that diagnosis is relatively simple and is, therefore, not modeled
    - Using the calculator, we can model diagnosis, action, or both

The SPAR-H Calculator (cont.)

Uncheck to ignore diagnosis



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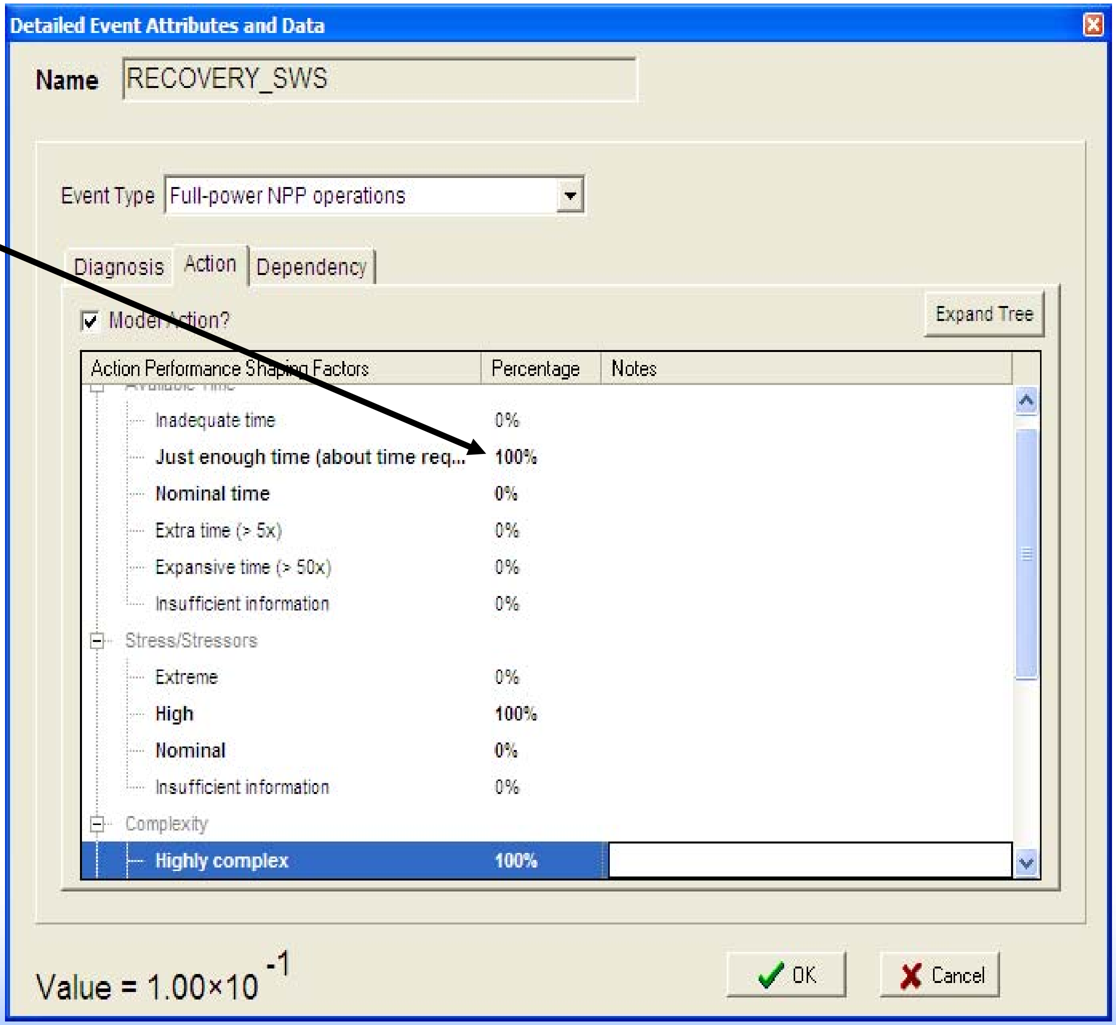
The SPAR-H Calculator (cont.)

- The second tab (see next page) allows us to model the action portion of the recovery task
- For the service water event we had
  - Just enough time
  - High stress
  - High complexity
- These PSFs have been set in the Calculator as shown on the following page
- Note that Calculator indicates the HEP is 0.1 (once the PSFs are adjusted)

The SPAR-H Calculator (cont.)

Modify the PSFs as needed

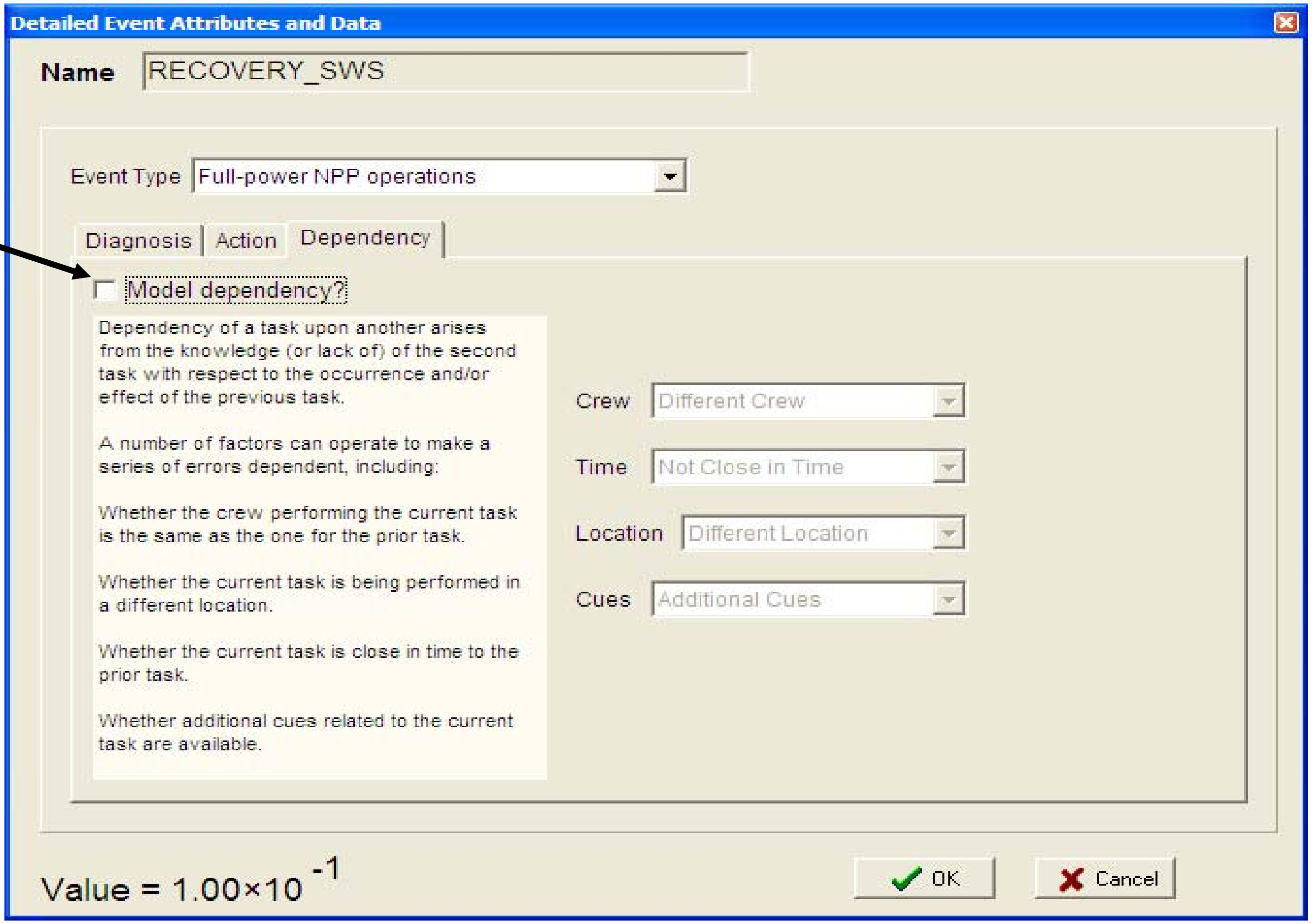


The SPAR-H Calculator (cont.)

- The third tab (see next page) allows for modeling dependency between actions
  - For example, if the crew had to recover another system prior to service water, then we would need to account for this possible dependency
- To account for dependencies, we utilize four factors
  - The crew (same or different)
  - The time (events close in time or not)
  - The location (same place or not)
  - The cues (new cues or not)
- For service water recovery, assume the action is independent of any other actions – thus no dependency

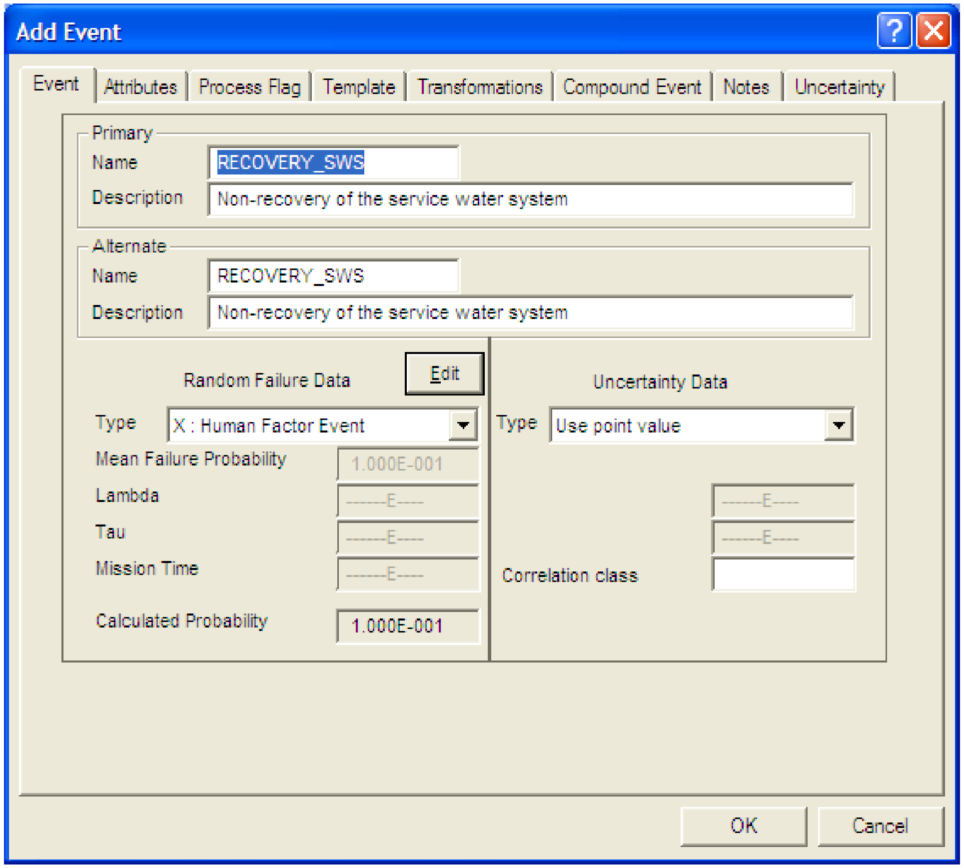
The SPAR-H Calculator (cont.)

Uncheck to ignore dependency



The SPAR-H Calculator (cont.)

- Finally, we would end up with the HEP as a basic event in our PRA
  - This event will appear in the “loss of service water” cut sets
  - Its overall value has a probability of 0.1



Class Exercise

- **Example of a medical error in radiation treatment of a patient taken from *Set Phasers on Stun* by Steven Casey:**
  - Ray Cox, 33, receiving ninth radiation therapy treatment after removal of cancerous tumor from his shoulder. Everything starting to become fairly routine, and he was quite comfortable with Mary Beth, his radiotherapy technician, and the THERAC-25 radiotheraphy machine. Ray lied face down on table. Mary Beth positioned the THERAC-25 and went into the control room. Mary Beth used a computer terminal to enter commands on THERAC-25. The video and audio between the patient room and the control room were not working. There were two modes: a high-power x-ray dose to radiate tumors and a low-power electron beam for subsequent treatment. Mary Beth accidentally put it in x-ray mode by typing [X] but then corrected it to electron mode by moving the cursor up and typing [E]. She then pressed [RETURN] to administer the treatment.

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Class Exercise (Continued)

- ***Set Phasers on Stun* (Continued):**
  - No one had every changed an [X] to an [E] before in this manner. Atomic Energy Canada, who developed the THERAC-25, had not anticipated this way of changing the mode. This error not only switched the THERAC-25 into x-ray mode, it disabled a metal plate that limited the intensity of the x-ray. Ray Cox's intended dose of 200 rads actually became 25,000 rads! Mary Beth activated the first beam but received an error message that sounded like the beam had not been applied. She tried again two more times. The first time, Ray Cox heard a frying sound and felt an excruciating stabbing pain in his shoulder. Rolling in pain, the THERAC-25 fired again, this time into his neck. Screaming in pain, a third dose went through his neck and shoulder. He ran out of the treatment room. Mary Beth, meanwhile, was unaware what had happened, but the THERAC-25 reported Ray had only received 20 rads. In fact, he had received 75,000 rads. Four months later, Ray died due to radiation overdose. He remarked, "They forgot to set the phaser on stun!"

Class Exercise (Continued)

- ***Set Phasers on Stun*** **(Continued):**

What Was Supposed to Happen

- Set patient on table
- Position THERAC-25
- Go to control room
- Enter prescribed dose
- Activate dose
- Retrieve patient

What Actually Happened

- Set patient on table
- Position THERAC-25
- Go to control room
- Enter prescribed dose
- Correct wrong entry
- Activate dose
- Error message
- Go back and reactivate
- Error message
- Go back and reactivate
- Patient flees

Class Exercise (Continued)

- ***Set Phasers on Stun* (Continued):**

What Was Supposed to Happen

- Set patient on table
- Position THERAC-25
- Go to control room
- Enter prescribed dose
- Activate dose
- Retrieve patient

What is the likelihood for entering and giving the wrong dose?

What Actually Happened

- Set patient on table
- Position THERAC-25
- Go to control room
- Enter prescribed dose
- Correct wrong entry
- Activate dose
- Error message
- Go back and reactivate
- Error message
- Go back and reactivate
- Patient flees

Class Exercise (Continued)

What is the likelihood for entering and giving the wrong dose?

- First, consider the relevant PSFs from SPAR-H

  – Available time
  – Complexity
  – Procedures
  – Fitness for duty
  - Stress/stressors
  - Experience/training
  - Ergonomics/HMI
  - Work processes

- Determine which PSFs apply, and which do not

Class Exercise (Continued)

- Next, consider if it is a diagnosis (cognitive) or action (behavior)
- Finally, consider the levels of applicable PSFs
  – Use the numbers in parentheses on this table
- Calculate the Basic HEP
  – Nominal HEP (1E-2 or 1E-3) x Time x Stress x Complexity x Experience x Procedures x Ergonomics x Fitness for Duty x Work Processes
  – Correct for too many PSFs
  – Adjust for Dependency

SPAR-H (NUREG/CR-6883)

PSFs	PSF Levels	HEP for Diagnosis[1]	HEP for Action[1]
Available Time	Inadequate time	1.0 (no multiplier)	1.0 (no multiplier)
	Barely adequate time	0.1 (10)	0.01 (10)
	Nominal time	0.01 (1)	0.001 (1)
	Extra time	0.001 (0.1)	0.0001 (0.1)
	Expansive time	0.0001 (0.1-0.01)	0.00001 (0.01)
Stress/ Stressors	Extreme	0.05 (5)	0.005 (5)
	High	0.02 (2)	0.002 (2)
	Nominal	0.01 (1)	0.001 (1)
Complexity	Highly complex	0.05 (5)	0.005 (5)
	Moderately complex	0.02 (2)	0.002 (2)
	Nominal	0.01 (1)	0.001 (1)
	Obvious diagnosis	0.001 (0.1)	N/A
Experience/ Training	Low	0.1 (10)	0.003 (3)
	Nominal	0.01 (1)	0.001 (1)
	High	0.05 (0.5)	0.0005 (0.5)
Procedures	Not available	0.5 (50)	0.05 (50)
	Incomplete	0.2 (20)	0.02 (20)
	Available, but poor	0.05 (5)	0.005 (5)
	Nominal	0.01 (1)	0.001 (1)
	Diagnostic/symptom oriented	0.005 (0.5)	N/A
Ergonomics/ HMI	Missing/Misleading	0.5 (50)	0.05 (50)
	Poor	0.1 (10)	0.01 (10)
	Nominal	0.01 (1)	0.001 (1)
	Good	0.005 (0.5)	0.0005 (0.5)
Fitness for Duty	Unfit	1.0 (no multiplier)	1.0 (no multiplier)
	Degraded Fitness	0.05 (5)	0.005 (5)
	Nominal	0.01 (1)	0.001 (1)
Work Processes	Poor	0.02 (2)	0.005 (5)
	Nominal	0.01 (1)	0.001 (1)
	Good	0.008 (0.8)	0.0005 (0.5)

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SPAR-H Exercise

- **See Appendix F**

ATHEANA (NUREG-1624; NUREG-1880)

A Technique for Human Event Analysis (ATHEANA)

- Purpose is to “develop an HRA quantification process and PRA modeling interface that can accommodate and represent human performance found in real events”
- Assumption is that HFEs with highly trained staff using considerable procedural guidance “do not usually occur randomly or as a result of simple inadvertent behavior” such as missing a procedure step
- Instead, such HFEs occur when:
  - The operator is placed in an unfamiliar situation where training and procedures are inadequate or do not apply
  - When some other unusual set of circumstances exists

ATHEANA Background

Use of ATHEANA to:

1. Identify plausible error-likely situations and potential error-forcing contexts

Error forcing contexts (EFCs)

- arise when combinations of PSFs and plant conditions create an environment in which unsafe actions are more likely to occur—a situation that is setting up the operator to "fail"

Unsafe actions (UAs)

- are actions taken inappropriately or not taken when needed that result in degraded safety; unsafe actions don't necessarily lead to an error

2. Define HFEs pertinent to performing human actions incorrectly
3. Determine HEPs

ATHEANA Background (Continued)

Unique Features of ATHEANA

1. Identify operational vulnerabilities the could set up UAs
   - E.g., procedure weaknesses
2. Identify plausible deviations from nominal scenarios

> **Nominal scenario**
> - The expected or representative case scenario included in the PRA

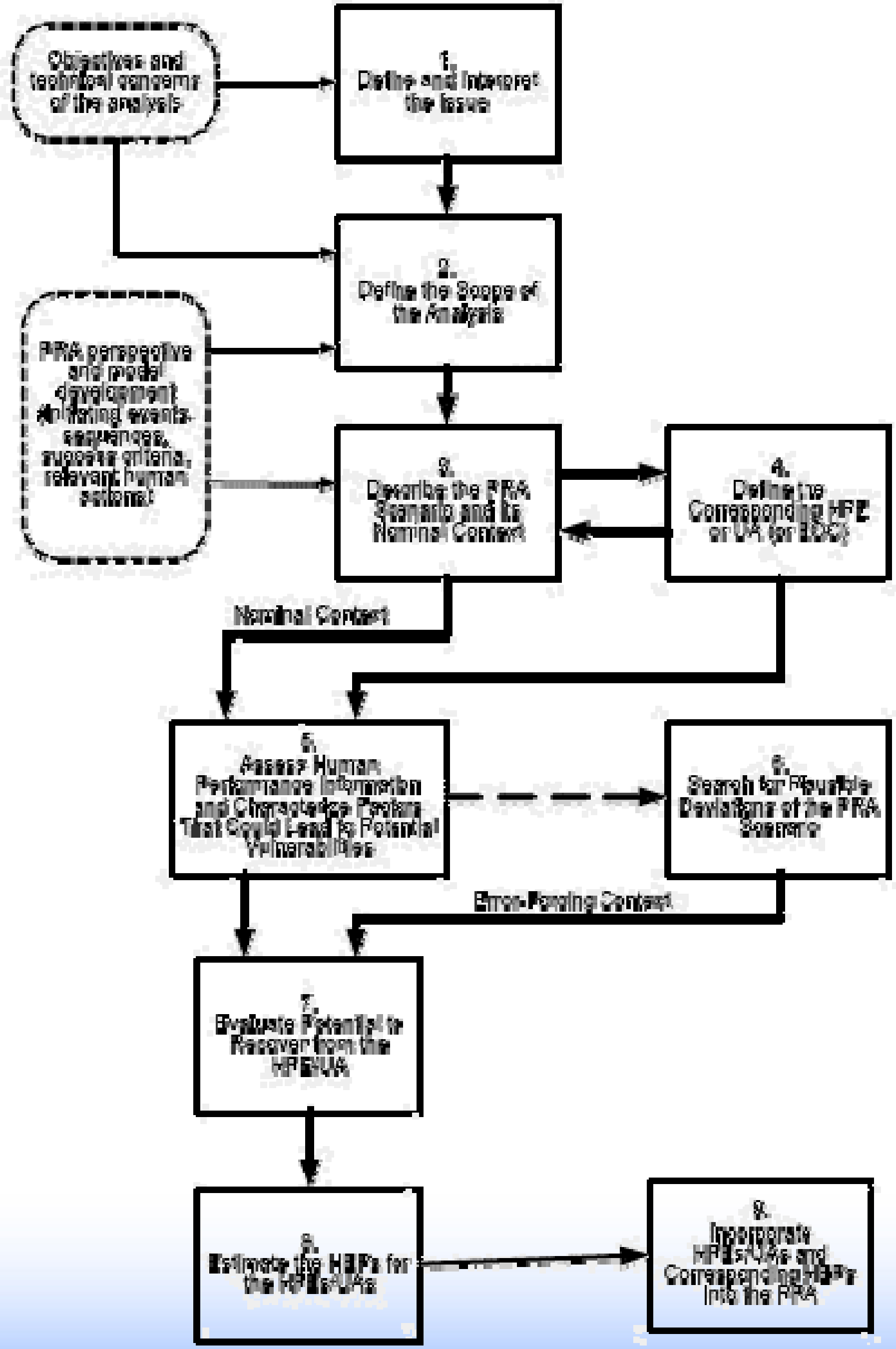
3. Identify important PSFs relevant to both nominal and deviation scenarios
4. Identify other factors that could significantly affect the likelihood of the HFEs

ATHEANA Background (Continued)

When to Use ATHEANA

- Use ATHEANA if risk-informed decision making requires:
  1. Understanding vulnerabilities associated with specific UAs instead of generic HFEs
     - E.g., submittal that includes procedural change
  2. Understanding the contexts of specific EFCs (rather than a generic scenario context)
     - E.g., need for a more detailed HRA as part of a PRA
  3. Understanding a wide range of PSFs under different contexts and scenarios
     - E.g., screening analysis reveals particular HFEs that are risk significant, and it is desired to have a thorough analysis of those HFEs

Steps of ATHEANA



Steps synthesize much of what has been covered in this course:

- Identifying errors
- Modeling errors in the PRA
- Quantify the errors using expert elicitation

Steps of ATHEANA (Continued)

Step 1: Define and Interpret Issue

- Assemble ATHEANA team
    - HRA analyst
    - PRA analyst
    - Operations expert
    - Operations personnel
- Get background information
- Identify audience to whom the issue resolution is to be provided
- Define the issue in HRA terms
- Provide an overall risk framework for resolving the issue

Steps of ATHEANA (Continued)

Step 2: Define Scope of Analysis

• Prioritize what is necessary

Step 3: Describe the Nominal Context

Step 4: Define the Corresponding HFE or UA

• Identify the human actions (HFE/UA) for the PRA

Step 5: Assess Potential Vulnerabilities

• Consider the time phases (e.g., pre-/post- initiator) for
the analysis

• Review influence of PSFs
    • PSF weights may vary from one context to another

Steps of ATHEANA (Continued)

Step 6: Search for Plausible Deviations from PRA Scenario

• Consider scenarios that can cause operators problems in detecting, understanding, or responding to situation

Garden path problems (Strong but incorrect evidence)	**Changing situations (Failure to notice new conditions)**
Missing information	**Misleading information**
Masking activities (Other activities may hide underlying problem)	**Multiple lines of reasoning (Conflicting strategies)**
Side effects	**Impasse**
Late changes in plan	**Dilemmas (Ambiguity causes doubt about appropriate action)**
Trade-offs	**Double binds (Two undesirable elements)**
High tempo, multiple tasks (Operator overload)	**Need to shift focus of attention**

Steps of ATHEANA (Continued)

Step 6: Search for Plausible Deviations from PRA Scenario (Continued)

- Screen out deviations that are not risk significant

Step 7: Evaluate Potential for Recovery

Step 8: Estimate the HEPs for the HFEs/UAs

- Use guided expert estimation approach with facilitator and panel of experts

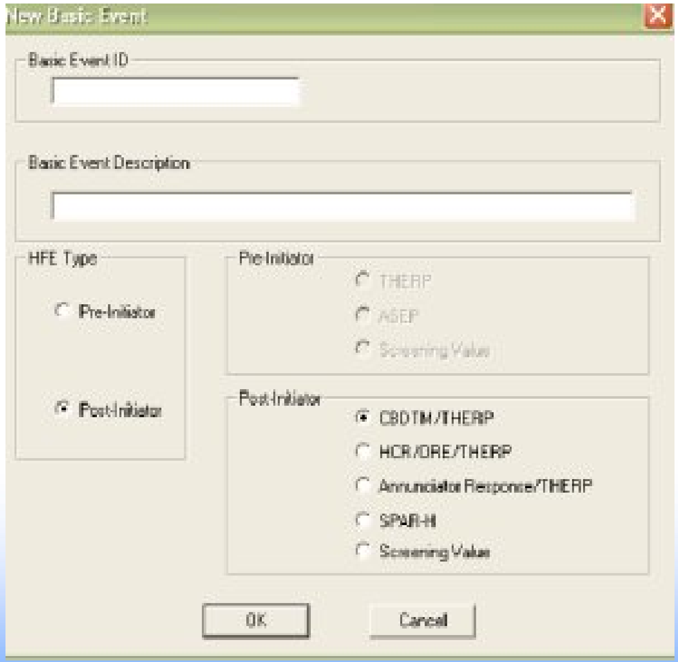
Step 9: Incorporate HFE/UA and HEP into PRA

Other HRA Methods

- As noted earlier, there are over 40 HRA methods
  – THERP, ASEP, and SPAR-H are the most common in use by the NRC
- Additional methods you may encounter from industry include
  – EPRI HRA Calculator
  – Or any of over 50 HRA methods

EPRI HRA Calculator

- Software tool to combine several HRA methods for quantifying pre- and post-initiator HFEs
- Includes
  - EPRI Cause-Based Decision Tree Method (CBDTM)
  - Human Cognitive Reliability/Operator Reactor Experiments (HCR/ORE)
  - ASEP
  - THERP
  - SPAR-H



EPRI HRA Calculator (Continued)

HCR/ORE Implementation:

- Linked to EPRI ORE data collection
- Control room operator actions
- Emergency and abnormal operating procedures based
- Similar to operator action tree approach
- Recognizes a time window exists for which functions must be completed
- Task decomposition required
- Nominal screening curve provided based on normalized time reliability curve
- Operator/crew performance influenced by cues and responses as indicated in procedures

EPRI Calculator (Continued)

CBDTM Implementation:

- Number of decision trees provided:
  - Data not available
    - Indication not available, inaccurate, warning not present in procedures, training on indicators not provided,
  - Data not attended to
    - Workload, one-time check versus continuous, front versus back panel, alarmed versus not alarmed
  - Data misread
    - Indicators not easy to locate, human engineering deficiencies, formal communications protocols present/ not present,
  - Information misleading
    - Are cues in procedures, indicator obviously failed, procedures warn of differences, specific training
  - Probability of crew response is adjusted for recovery.

Choosing Between Methods

Advantages of Each NRC Method

- Full Qualitative Analysis
  - THERP, ATHEANA
- Simplicity of Estimation Process (Screening Tool)
  - ASEP, SPAR-H
- Flexibility to Cover Unusual Events
  - ATHEANA
- Coverage of Cognitive Factors
  - SPAR-H, ATHEANA
- Complete Method (Identification, Modeling, Quantification)
  - THERP, ATHEANA

Remember, there are over 50 HRA methods that may meet particular applications beyond what has been described here

- Distilling the most useful methods for particular applications is task of ongoing NRC projects under Dr. Erasmia Lois
  - Shift from developing new methods to validating existing methods

LESSON 8

HRA Good Practices

HRA Good Practices (NUREG-1792)

- Developed in response to NRC activities to address quality issues in PRA
- Meant to be generic, not tied to a specific HRA method, “to ensure consistency and quality” (p. 5)
- Linked to RG1.200, ASME STD RA-S-2002 Standard for PRA for Nuclear Power Plant Application, and NEI -00-02 Rev 3 PRA Peer Review Process Guidance
- Addresses Pre-Initiator HRA, Post Initiator HRA, errors of commission, and good practices audits

Good Practices for HRA in PRA

Specifies the human failure events (HFEs) modeled in PRAs that are associated with <u>normal plant</u> operations including:

- events leaving equipment in an unrevealed, unavailable state
- those that induce an initiating event (e.g., human induced loss of feedwater)
- those modeled as human events contributing to an initiating event (e.g., total loss of service water event, failing to start service water train B upon loss of A)

Specifies the HFEs modeled in PRAs associated with emergency operation including:

- Events that, if not performed, do not allow a desired function to be achieved, such as failing to initiate feed and bleed

Good Practices PSFs

The following PSFs should, at a minimum, be considered in analyses:

Good Practices PSFs (NUREG-1792)
Training and Experience
Procedures and Administrative Controls
Instrumentation
Time Available
Complexity
Workload/Time Pressure/Stress
Team/Crew dynamics
Available Staffing
Human-System Interface
Environment
Accessibility/Operability of Equipment
Need for Special Tools
Communications
Special Fitness Needs
Consideration of 'Realistic' Accident Sequence Diversions and Deviations

Other Good Practices

- Guidance in NUREG 1792 pertains to practices to determine the result of human actions as realistically as <u>necessary</u> in an assessment of risk
- Good practices to be determined with the intent of the particular PRA application in mind. For example, in some cases it may be appropriate to use complete dependency to assist in screening analysis.
- Contains a cross reference table to the *ASME Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications* (ASME RA-S-2002; see course CD; 2008 revision now published)

Sample Good Practices

- Involve a multidisciplinary team
- Perform walk downs
- Identify pre-Initiators (look at procedures and actions; consider test and maintenance, calibration that could affect equipment credited in the PRA; determine whether misalignment or miscalibration could make equipment unavailable)
- Do not ignore pre-initiators
- Examine other operational modes and routine operations that could affect outcome
- Consider other barriers and structures such as fire doors, drains, seismic restraints, etc.
- Screen out actions that have acceptable restoration signals, and checks or signs that help ensure that equipment will be reliably restored

Sample Good Practices (Pre-Initiators)

- If actions affect multiple (redundant or diverse) equipment do not screen
- Quantify – Use screening values if they are conservative and values can account for dependency
- Account for PSFs
- Account for plant specific recovery factors (compelling signals, testing, scheduled checks, independent verifications, etc.)
- Consider multiple recoveries or opportunities, but consider the possibility of dependencies among opportunities
- Consider dependencies among HEPs in the accident sequence
  - Assess uncertainty in mean HEP values (excluding screening HEPs)
  - Evaluate HEP reasonableness (relative to one another and in absolute terms)

Sample Good Practices (Post-Initiators)

- Review post initiators procedures and training (AOP, EOP and SAMGs)
- Review fire procedures as needed
- Review simulator training as available
- Identify post initiator actions by review of above in conjunction with plant functions, systems, and equipment as modeled in the PRA
- Determine how operators are to respond to different equipment failure modes
- Look with certain types of actions in mind
- Model specific HFEs needed in the PRA
- Review the nature of the action, consequences, nature of sub-tasks involved and level of detail already present in the PRA
  - Failure modes should be linked closely to failed equipment being modeled

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Sample Good Practices for Post Initiators (Continued)

- Perform walk downs and talk-throughs, asking:
  - Who does what?
  - How long does it take?
  - Are there special tools or environmental issues?
- Quantification should consider both cognitive and response execution failures, use screening values initially (conservative enough to be overestimations), and conservatively account for dependencies
  - Individual values should never be < 0.1
  - Joint probability of multiple HEPs in a sequence never < 0.05
- Evaluate screening versus detailed analysis
- Account for plant activity and PSFs (many listed)
- Account for dependencies among post initiator HFEs

Sample Good Practices for Post Initiators (Continued)

- Address uncertainty (e.g., propagate uncertainty distributions and perform sensitivity analysis that demonstrates effects of risk results)
- Check for reasonableness: relative to one another, in absolute terms
- Define appropriate recovery actions
  - Consider the time and whether cues will be clear
  - Consider the most logical actions that apply
  - Do not include repair
- Consider dependencies
- Quantify the probability of failing to perform the recoveries
  - Use representative data or HRA methods
  - Identify EOCs or the conditions that would make EOCs more likely (largely problems in information available to crews-- incomplete, missing, misleading, ambiguous, no guidance, etc.)
  - Document quantification assumptions and decisions!

Good Practices Bare Bones: Look for Expected Types of Actions

In HRA:

- Include necessary and expected activities
  - Initiate RHR
  - Control vessel level
  - Isolate faulted SG
  - Etc.
- Include backup actions to failed automatics
  - e.g., manually start DG
- Include procedure driven or skill of the craft recovery
  - Restore offsite power
  - Align firewater backup
  - Etc.

Summary of NUREG-1792

- Good explanations and examples
- Not method specific
  - Method comparisons provided in accompanying NUREG-1842 (see CD)
- For reactor, full power, internal events
- Supports REG Guide 1.200 (2004)
- Two main purposes:
  - Guidance for performing HRAs
  - Support the review of HRAs

Taken in part from: *New Scientist 2 November 1991*

The Fallible Engineer

Australian engineers feel that they are being blamed for accidents and failures that are beyond their control. They want the public to understand that experts are only human.

Sharon Beder

At four o'clock in the morning of 30 April 1988, a railway embankment near the coastal town of Coledale in New South Wales collapsed, sending tons of mud and water down a hill. The debris crushed a house, killing a woman and child who were inside. The area was prone to subsidence and evidence given at the inquest suggested that the designers of the embankment had not taken proper account of this. Four people, two of them engineers, were subsequently charged with endangering passengers on a railway. One, a principal geotechnical engineer with the State Rail Authority of New South Wales, was also charged with two counts of manslaughter.

Though none of them was convicted, the engineering profession was horrified that engineers should be charged in this way, and rallied to their support. Peter Miller, chairman of the standing committee on legal liability of the Institution of Engineers, Australia, argued that criminal prosecutions against engineers set a precedent that could change the way engineering was practiced. He said it was likely to result in engineers becoming more conservative in their assessments and decisions. Although this was not in itself a bad thing, it would mean higher costs for engineering work, he claimed.

The institution was also concerned about individual blame being apportioned to engineers who work as part of a team in organizations operating under financial constraints. Bill Rourke, who retired last month as the institution's chief executive, pointed out in its magazine, *Engineers Australia*, that safety margins are closely related to the availability of funds. He argued that the provider of those funds, in this case the community, should carry a significant responsibility for safety levels.

The issue of who should take responsibility when things go wrong is becoming a central concern for the engineering profession worldwide. At the end of last year the Australian institution sent all its members a discussion paper entitled *Are you at risk? Managing Expectations.* More than 3000 engineers replied, the largest response the institution has ever had on any issue. In the preface to the paper, the institution's president, Mike Sargent, said that the trend towards criminal prosecutions for negligence and escalation of civil law claims against engineers "constitute a significant threat to the ability of our profession to serve the community and might even threaten its continued existence."

Miller, too, believes that the profession is at risk. "Engineers are being put in untenable positions," he says. "they are being asked to make decisions over matters they cannot control and being forced to take responsibility for these decisions." What Miller and his colleagues at the Institution of Engineers are proposing is nothing short of a radical change in the relationship between engineer and society. The engineering profession seems to be approaching a turning point.

Miller and his colleagues believe that if people are more aware of the uncertainties surrounding engineering work and the limitations of mathematical models, then they would not so readily blame engineers for failures. The institution's discussion paper pointed out that engineers had presented a falsely optimistic and idealistic view of their work. They are now paying the price for having raised unjustifiably high the public's expectations of what they can deliver. "We know (or should know) that our models are limited as to their ability to represent real systems, and we use (or should use) them accordingly. The trouble is that we are so inordinately proud of them that we do not present their limitations to the community, and leave the community with the impression that the models are precise and comprehensive."

The discussion paper quotes the 1946 chairman of the Scottish branch of Britain's Institution of Structural Engineers as saying: "Structural engineering is the art of modeling materials we do not wholly understand into shapes we cannot precisely analyse so as to withstand forces we cannot properly assess in such a way that the public at large has no reason to suspect the extent of our ignorance."

Why have engineers misled the public in this way? Gavan McDonnell, an engineer and supervisor of the graduate program in science and society at the University of New South Wales, says: "It is the very nature of professions to fill the role of a sort of priesthood with transcendental access to superior knowledge. Engineers have assumed this role, too. They have protected their professional status as possessors of special knowledge and have not been inclined to discuss the limitations of that knowledge with those outside the profession." McDonnell admits that there is a large element of technocratic arrogance in this stance, but says that modern societies require this division of knowledge in order to function. There is, however, an important rider: "Previously the community trusted in the probity and ethical rightness of the expert," he says. "But as experts are increasingly seen to be working for particular interests in society, that trust is disappearing."

Miller, too, points to the breakdown of the social contract between engineers and society. He says that the contract involved a commitment by engineers to always put the public interest first and a commitment by the public to allow engineers to regulate themselves. "That contract is now seen to be broken by both parties," he says. The institution's discussion paper is the first step in a process of re-establishing trust between engineers and the public. Miller, one of the authors of the paper, was at first hesitant about sending it out. He was worried that engineers might not be interested in questions that don't have clear-cut answers, and concerned that they would not want to discus philosophy—even engineering philosophy. He has been gratified to find an unsuspected hunger for such a discussion.

The philosophy set out in the paper is that engineering is an art rather than a science, and as such depends heavily on judgment. The widespread use in engineering of heuristics, or "rules of the thumb," requires judgment to be used properly. Billy Vaughn Koen, professor of mechanical engineering at the University of Texas at Austin, defines a heuristic device as "anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification and infallible." Heuristics is used in the absence of better knowledge or as a short-cut method of working out something that would be too expensive or too time-consuming to work out more scientifically.

An example of a heuristic device is a "factor of safety," sometimes referred to as a "factor of ignorance." Engineers have to work with materials that vary widely in strength and other characteristics, and design for a range of operating conditions and loads. To cope with these variations and uncertainties they employ factors of safety. Henry Petroski, an American engineer who has written extensively on engineer accidents, explains: "Factors of safety are intended to allow for the bridge built of the weakest imaginable batch of steel to stand up under the heaviest imaginable truck going over the largest imaginable pothole and bouncing across the roadway in a storm."

However, the concept of a factor of safety is often misunderstood by those outside the profession as implying some large safety margin on a predictable design. Barry McMahon, a Sydney-based geotechnical engineer, has found his clients believe that as factor of safety implies "certainty" plus a bit more. He says they are far more concerned with the financial risk of "conservative" design (design that errs on the safe side) than they are with other sources of risk. Conservative design tends to be more expensive, which means that there is always pressure to reduce factors of safety. For a factor of safety to be effective, the means of failure must be known and the cause of the failure determinable by experiment. For example concrete columns may be designed to cope with 10 times the compression stresses the engineer estimates they will have to bear. In this case the factor of safety is 10. But this assumes that if the columns are going to fail it will be as a result of compression.

If the columns are subject to unexpected forces from another direction—so that they are stretched instead of compressed, for example—then their extra ability to take compression will not be of much help. The ability of a concrete column to bear a particular stress is determined by experiments done repeatedly on concrete columns in the laboratory.

All engineering structures incorporate factors of safety and yet some still fail, and when this happens the factor of safety for similar structures built subsequently might be increased. Conversely, when a particular type of structure has been used often without failure, there is a tendency for engineers to suspect that these structures are overdesigned and that the factor of safety can be reduced. Petroski says: "The dynamics of raising the factor of safety in the wake of accidents and lowering it in the absence of accidents can clearly lead to cyclic occurrences of structural failures." He points out that this cyclic behaviour occurred with suspension bridges following the failure of the Tacoma Narrows Bridge, which collapsed spectacularly in 1940 in mild winds.

Cutting safety margins to reduce costs in the face of success happens in all engineering disciplines. William Starbuck and Frances Milliken, researchers at New York University, have studied the catastrophic failure of the challenger space shuttle in January 1986 and concluded in their paper "Challenger: fine-tuning the odds until something breaks" (*Journal of Management Studies*, Vol. 25, July 1988) that the same phenomenon was present there. They argue that, as successful launches accumulated, the engineering managers at NASA and Thiokol, the firm responsible for designing and building the rocket boosters for the shuttle, grew more confident of future successes. NASA relaxed its safety procedures, treating the shuttle as an "operational" technology rather than a risky experiment, and no longer tested or inspected as thoroughly as they had the early launches.

Signs of Failure

The O-rings sealing the joints in the shuttle's solid-fuel rocket booster, which were eventually found to have played a major role in the accident ("Why Challenger Failed," *New Scientist*, 11 September 1986), had shown signs of failure in after three of the five flights during 1984 and after eight of nine flights during 1985. But since this damage had not impeded the shuttle launch, engineering managers at NASA and Thiokol came to accept this damage as "allowable erosion" and "acceptable risk." Lawrence Mulloy, manager of the solid rocket booster project, is quoted by Starbuck and Milliken as saying: "Since the risk on O-ring erosion was accepted and indeed expected, it was no longer considered an anomaly to be resolved before the next flight."

Brian Wynne, a researcher at the University of Lancaster, has also studied the Challenger disaster and other accidents. He says that O-ring damage and leakage had come to be accepted as "the new normality." Wynne argues that implementing designs and operating technological systems involve "the continual invention and negotiation of new rules and relationship" and that if this did not happen most technological systems would come to a halt. Starbuck and Milliken agree with respect to the space shuttle. They point out that NASA had identified nearly 300 special "hazards" associated with the launch of Challenger. "But if NASA's managers had viewed these hazards so seriously that any one of them could readily block a launch, NASA might never have launched any shuttles."

Wynne says there is a tendency to refer to "human error" when accidents occur, as if there has been some "drastic departure from normal rule-bound operating practices, and as if we were exonerating a supposedly separate mechanical, nonsocial part of the system." He suggests that part of the problem may be that technological systems are designed as if organizations can operate with perfect communication and that people are not prone to distraction, illogic or complacency. Jean Cross, professor of safety science at the University of New South Wales, agrees that engineers have a tendency to neglect what she calls the "human/technology interface" in their designs. For example, they do not take account of how long it takes people to process information and how people behave when they are under stress.

The institution's paper gives some recognition to this. It says that the notional probability of failure implicit in engineering codes does not give sufficient weight to human factors. "It deals mainly with those issues for which we can rationally compute factors of safety." Miller is keen for engineers to give more consideration to the human/technology interface. This is one of the areas that will be covered in a second discussion paper, which is being put together at the moment.

For Starbuck, Milliken, Wynne, Petroski and many others, all engineering design involves experimentation. According to Petroski, "each novel structural concept—be it a sky walk over a hotel lobby, a suspension bridge over a river, or a jumbo jet capable of flying across the oceans—is the hypothesis to be tested first on paper and possibly in the laboratory but ultimately to be justified by its performance of its function without failure." Failures will occasionally occur. They are unavoidable, he argues, unless innovation is completely abandoned.

Wynne goes further, arguing that the experimental nature of engineering extends beyond the designing stage: "If technology involves making up rules and relationships as its practitioners go along, it is a form of social experiment on the grand scale." Similarly, Starbuck and Milliken say that "fine tuning is real-life experimentation in the face of uncertainty."

If engineering is based on incomplete models and on judgment and experimentation, who should be held responsible when engineering projects fail, causing loss of life and property, and damage to the environment? For many engineers this is not a useful question. Mark Tweeddale, professor of risk engineering at the University of Sydney, argues that finding who is to blame for an accident is a fruitless way of going about things. "If someone makes a mistake, you need to ask what caused them to make that mistake? Was it the stress they were under? Was it that they were not properly trained? Should they never have been hired for the job? All these questions lead back to management, but management is also human and the same questions apply. It's like peeling an onion: in the end you are left with nothing." This does not mean an accident shouldn't be investigated. But Tweeddale feels that legal proceedings to establish blame are unhelpful in sorting out the lessons to be learnt from an accident, because the sub judice laws that come into play during a court case restrict free and open public discussion of what happened.

Engineers feel that the public is increasingly looking for someone to blame when accidents happen, rather than accepting accidents as an inevitable part of life. They are frustrated at what seems to be the public's requirement for complete safety. Simon Schubach, a consulting engineer who does risk assessments for the New South Wales planning department, is often asked at public meetings: "Will it be safe?" But the audience seldom accepts his answer, which tends to be along the lines of: "On the basis of the assumptions we made, and the limited applicability of the models we used, our assessment is that the project will meet acceptable risk criteria." Schubach finds the public's demand for certainty naïve, unreasonable, and ill-founded: "Engineering is just not like that."

McDonnell is also concerned about the increasing tendency for lawyers to look for someone to hold liable whenever anything undesirable happens after engineers have given advice. However, he argues that the law still has a part to play where there has been gross negligence and dereliction of duty. This may mean criminal prosecutions of engineers in some instances," he says. "Engineers simply can't expect to be immune from this."

Australia's Society for Social Responsibility in Engineering believes that engineers should accept responsibility for safety of their work even if this means they will be held criminally liable. Philip Thornton, president of the society, says: "If an engineer makes a structure stronger because the risk of being charged if that structure collapses is too high, then the risk of someone being killed or injured is also too high." Thornton argues that if engineers are concerned about being personally liable for accidents and failures then they are less likely to bow to economic pressure to reduce safety margin. "Caution is a good thing."

The dilemma for engineers today is how to tell the public of the extent of their ignorance without losing the community's confidence. Getting public acceptance of new or controversial technologies is greatly assisted by portraying them as perfectly predictable and controllable. "Concern for public reassurance produces artificially purified public accounts of scientific and technological methods and processes," says Wynne. "When something goes wrong, this background is an ever more difficult framework against which to explain that even when people act competently and responsibly, unexpected things can happen and things go wrong."

The emerging recognition that this situation cannot go on is leading Australian engineers to question their role as "problem solver" who design projects and advocate them as the "right" solutions to community problems. The Institution of Engineers is suggesting a shift to a different role for engineers as "technical advisers" who put forward options for the community to choose from. This means forgoing some of their autonomy and status as technological decision makers in favor of sharing the decisions, in order to share the responsibility of things go wrong. McDonnell argues that the social contract between engineers and the community will not disintegrate if ways can be developed of consulting the public and allowing the community to monitor and vet projects.

It will not be easy for people like Miller and his like-minded colleagues in the Institution of Engineers to bring engineers around to this sharing of responsibility and decision making, and to open and frank dialogue with the community. The change will require a lot more discussion within the profession and changes in engineering education and perhaps public education. Yet Miller is heartened by the overwhelmingly positive response he has had from engineers in Australia.

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Further reading: *Are you at Risk? Managing Expectations.* Institution of Engineers, Australia, 1990; Henry Petroski, *To Engineer is Human: The Role of failure in Successful Design,* MacMillan 1985; Brian Wynne, "Unruly technology: Practical rules, impractical discourses and public understanding," *Social Studies of Science*, Vol 18, 1988; William Starbuck and Frances Milliken, "Chalenger: fine-tuning the odds until something breaks," *Journal of Management Studies,* Vol 25, July 1988.

Event A Description (from NUREG/CR-6088)

Event A involved the high dose rate (HDR) remote brachytherapy treatment modality and was categorized as a misadministration involving delivery of a dose to the wrong site.

Description of the event. On the afternoon of November 27, 1991, the day before Thanksgiving holiday, a male patient scheduled to receive his fifth and final radiation therapy treatment for cancer of the nasal septum was placed in the HDR treatment room. A catheter was attached to the patient's nose. A trained resident physician attached this catheter to the HDR unit. When the patient was ready to be treated, a physicist was paged to operate the unit. The physicist who operated the HDR unit during this particular patient's first four treatments was not available. A second authorized physicist proceeded to the treatment area where he picked up a patient's chart located to the left of the HDR console and programmed the unit's computer with the treatment card taken from the chart. Entry of the information from the treatment card into the unit's console produced a printout of the treatment parameters (source dwell times and positions). The HDR unit was activated after the physicist and the resident physician verified that the treatment parameters on the chart corresponded with those on the printout. As the treatment began, one of the three observers standing near the console inquired about the length of the treatment. The resident physician indicated that the treatment would last about one and one half minutes, whereas the physicist indicated a time greater than 400 seconds. Based on this disparity, the resident physician reviewed the chart and discovered that it did not belong to the patient being treated. The appropriate patient chart had been placed to the right of the console. The unit was reprogrammed with the correct information and the treatment progressed normally.

Consequences of the Misadministration. As a result of using the wrong treatment parameters, the licensee reported that the patient's lips received an unintended dose of 76 cGy. As of the date of the team visit, the licensee reported that the patient had not exhibited any adverse aftereffects as a result of the misadministration.

Event G Description (from NUREG/CR-6088)

Description of the Event. On November 16, 1992, an 82-year-old female patient was undergoing radiation therapy for an anal carcinoma. The radiation therapy was to be administered by a HDR afterloader with five connecting catheters. For that day's treatment, a dose of 6 Gy (600 rad) was to be administered through five catheters implanted as a single-plane perineal (rectal) implant encompassing the tumor. After a trial run through the five catheters with a dummy source, the Ir-192 source was easily placed in four of the five catheters. After several unsuccessful attempts to insert the source into the fifth catheter, the physician directed termination of the treatment. An area radiation monitor in the treatment room was observed in an alarm condition—flashing red light—at some point during the unsuccessful attempts to insert the source into the fifth catheter. Although three technologists and the physician were aware of the alarm, no one used the available portable survey meter to detect whether radioactivity was present. Believing that the area radiation monitor was malfunctioning, they reset the area radiation monitor and returned the patient to a local nursing home without performing any radiological surveys. The staff were unaware that the Ir-192 source had remained in the patient.

The patient was returned to the nursing home where she resided with four of the original five treatment catheters, one containing the Ir-192 source, in place. One loose catheter had been removed at the clinic. The source remained in the patient's body for almost four days. On the fourth day, the catheter with the source came loose, and early on the morning of November 20, 1992 the catheter fell out. The patient died on November 21, 1992.

Consequences of the Misadministration. The NRC's medical consultant determined that the radiation the patient received from the Ir-192 source was a probable contributing cause of her death.

CHAPTER 20. TABLES OF ESTIMATED HUMAN ERROR PROBABILITIES

Overview

This chapter summarizes the estimated human error probabilities (HEPs) and their uncertainty bounds (UCBs) (or error factors [EFs]) presented in Part III. The tables in this chapter are duplicates of data tables in Part III except for changes to footnotes and table references to make them appropriate to Chapter 20. Not all data tables in Part III are included in this chapter; those that are included are sufficient for most human reliability analyses (HRAs) conducted as part of a probabilistic risk assessment (PRA). These tables are intended for use as quick references and are cross-referenced to the chapters from which they are drawn. The user is urged to familiarize himself with the source chapters for the proper use of the error terms and the assumptions on which they are based.

This chapter begins with a brief discussion of performance shaping factors (PSFs), followed by a search scheme for the use of the tables, with an explanatory talk-through of the search scheme. The chapter concludes with a list of tables, a quick-reference guide to the tables, and the set of tables.

For users conducting HRAs, the search scheme provides guidance to the appropriate tables at each stage of the analysis. The quick-reference guide is intended for general use and will help the analyst locate any table of interest.

Performance Shaping Factors

All of the estimated HEPs in the data tables are nominal HEPs, i.e., they represent HEPs before plant-specific PSFs have been taken into account. When these latter are evaluated, a nominal HEP may be modified upward or downward.

Chapter 3 describes the usual PSFs that influence HEPs in industrial settings. PSFs specific to classes of activities are discussed in detail in Part III. As a rule, the HEPs in the Handbook are based on "average" industrial conditions. We define average industrial conditions as those that do not subject a worker to an unusual degree of discomfort and that are fairly representative of the industry. The user may modify the tabled HEPs if the PSFs for his specific application are not average. Some guidance is given to help the analyst to determine the average conditions applicable to each group of HEPs, but most of this information is presented in Part III.

PSFs such as temperature, noise level, lighting, and others related to the comfort or health of the worker will usually be average (or better) in nuclear power plants (NPPs). This is because regulatory agencies such as the Nuclear Regulatory Commission and the Occupational Safety and Health Administration have developed "guidelines" or "recommended limits" for most controllable factors affecting workers. The plants' managements will work to meet the standards set by such agencies, and organizational units such as employee unions and professional organizations will usually report any deviations from these standards.

The PSFs related to ergonomics considerations are not subject to regulation. Hence, considerable variations exist from plant to plant as well as within any given plant. The estimated HEPs summarized here are based on conditions observed in a number of operating U.S. and foreign plants. In some cases, differences in PSFs have been estimated in the breakdown of the HEPs. For example, modifications to HEPs based on the PSFs of display type and information displayed have been defined in the data tables. Display types such as analog meters, digital indicators, chart recorders, etc., have been analyzed for the effect they have on human performance; the HEPs for errors made in dealing with displays have been modified to account for these effects. Very small differences in performance that might result from relatively minor differences in human factors engineering of displays, e.g., indicator needle length and width, are not represented in the estimated HEPs.

In other cases, it is not possible to provide quantitative estimates of substantial differences in levels of a PSF. For example, for the PSF of the quality of administrative control, the user will have to be content with rating this PSF as "good," "average," or "poor," making a subjective decision about the effect of this PSF on any particular task. Guidance is given for evaluating the effects of these types of PSFs, but considerable judgment by the analyst will be required.

The UCBs (or EFs) for an HEP reflect the estimated range of variability in performance attributable to differences in relevant PSFs, differences between and within people, differences in analysis, modeling uncertainty, and uncertainty about the actual HEPs. The tabled UCBs are speculative; the analyst may wish to expand them to indicate greater uncertainty. The tables list the EFs or UCBs for most of the HEPs, and Table 20-20 presents guidelines for estimating them for the other HEPs and for adjusting the tabled UCBs for stress and type of task, e.g., dynamic rather than step-by-step, as defined in Table 20-16.

Search Scheme for Use of Chapter 20 Tables

A search scheme is presented in Figure 20-1 to aid the analyst in considering all tables of HEPs that he should consult in an HRA. This search scheme is organized according to the outline of a Technique for Human Error Prediction (THERP) procedure for HRA, as presented in Figure 5-6 and discussed in Chapter 5. The heavy lines in the search scheme represent the paths of HRA activities we have most often employed in HRAs of NPP operations. Ordinarily, the analyst will have completed an initial task analysis and a set of first-cut HRA event trees before using the search scheme. He is now ready to assign HEPs to the failure limbs in the trees. The search scheme uses the flowchart format to guide the analyst through the essential steps in the conduct of an HRA, indicating the appropriate tables to which to refer at each stage of the analysis. It is assumed that if the

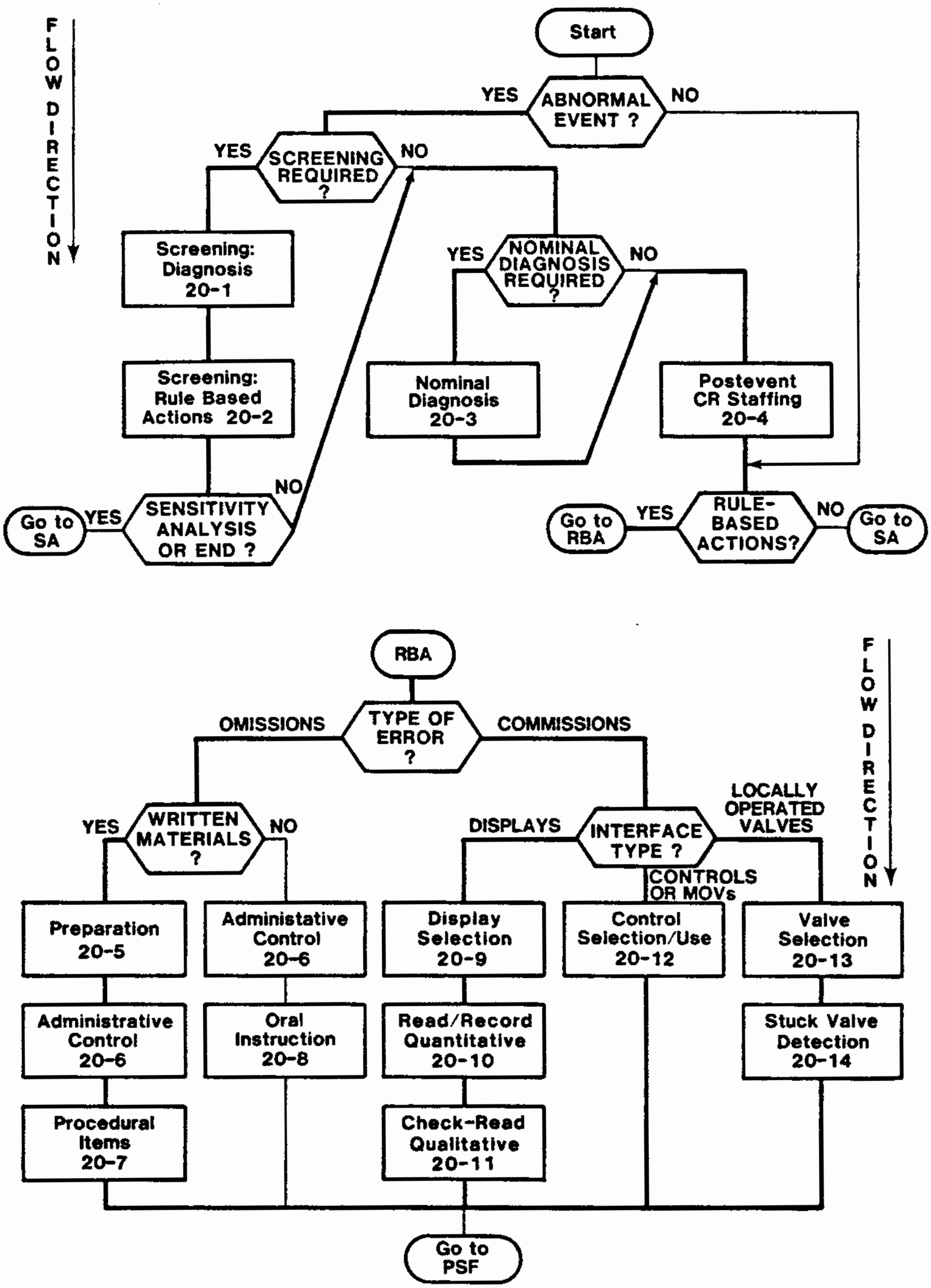

Figure 20-1 Search scheme for use of Chapter 20 tables (p 1 of 3).

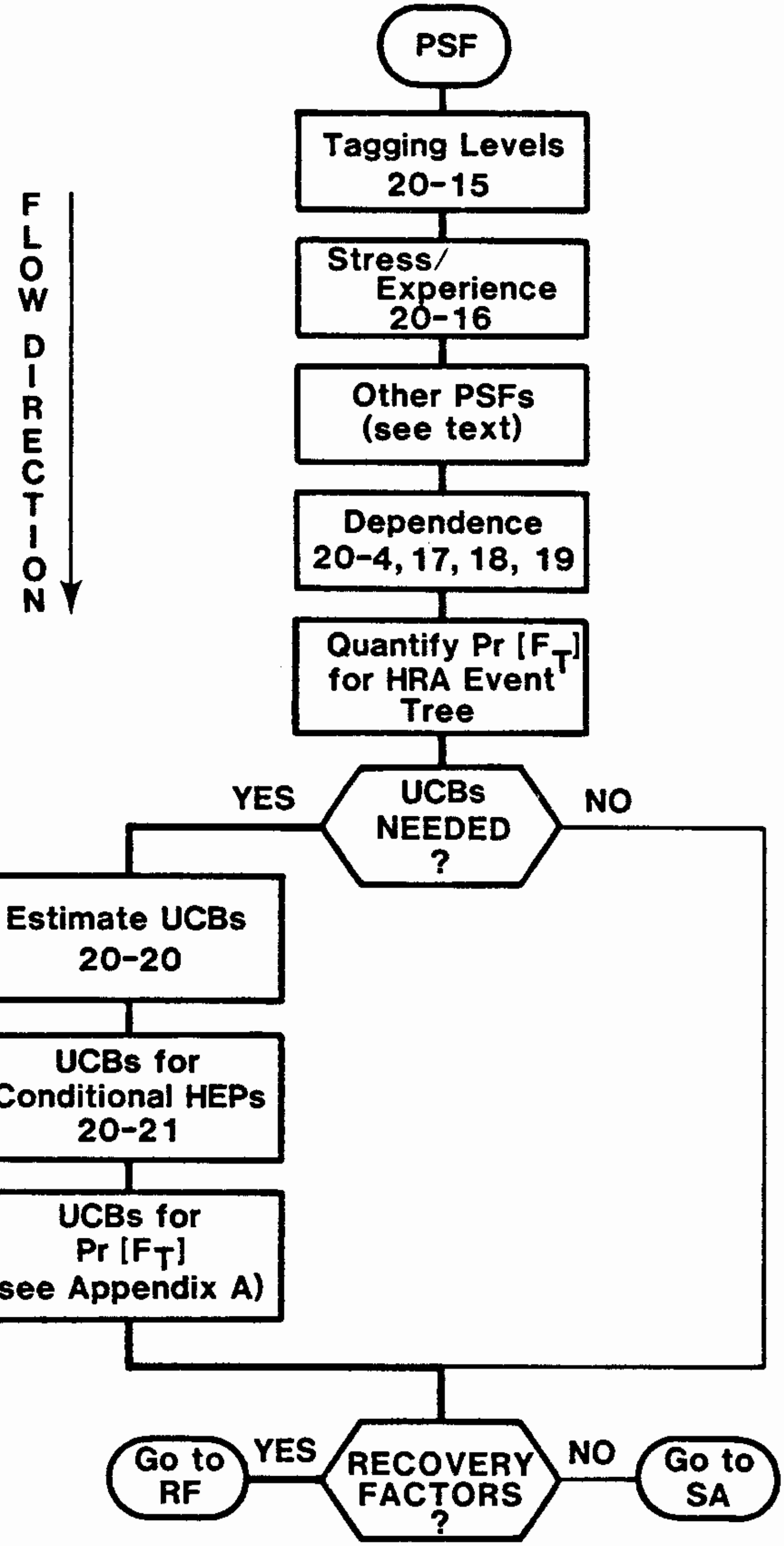

Figure 20-1 Search scheme for use of Chapter 20 tables (p 2 of 3).

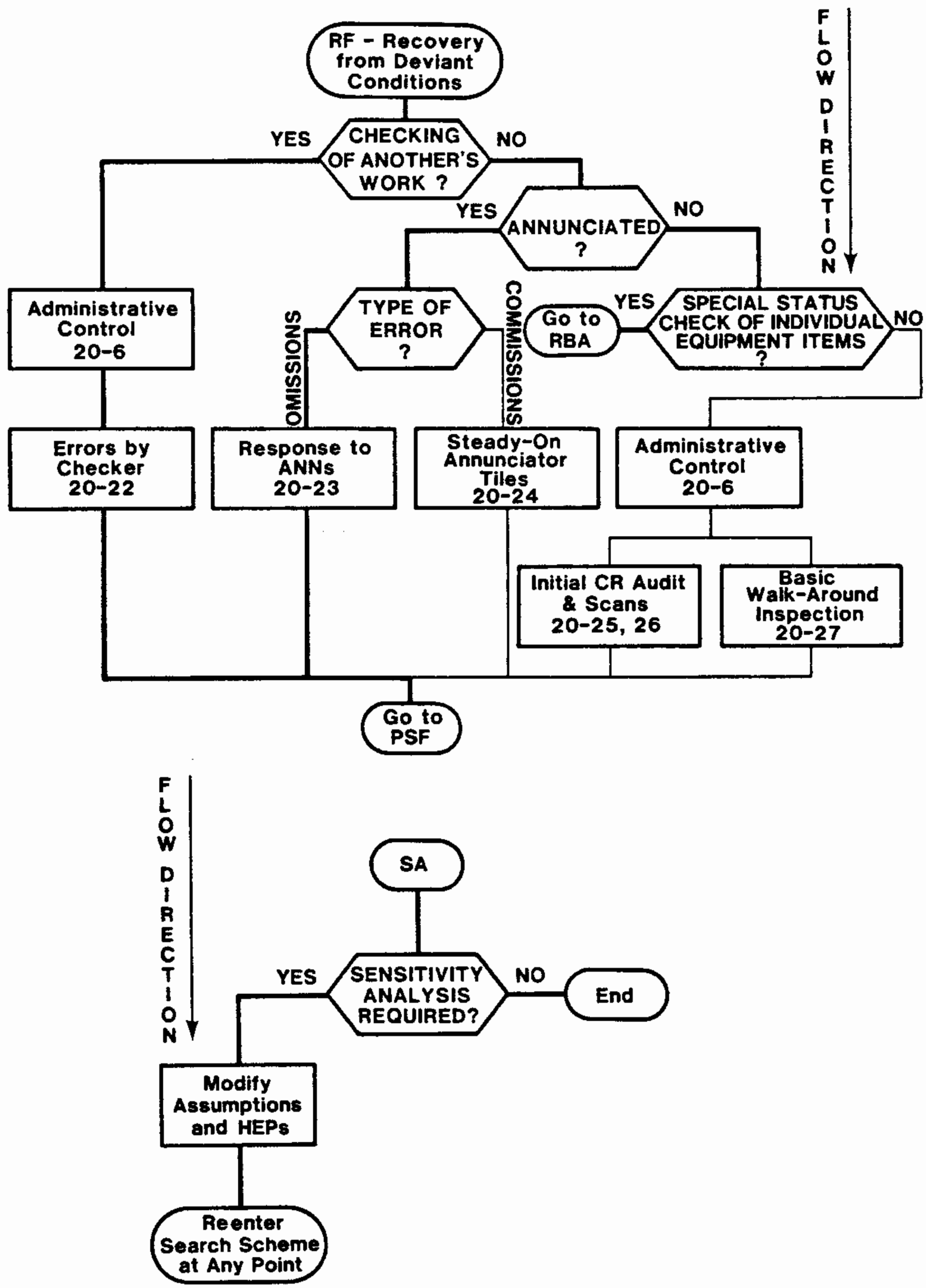

Figure 20-1 Search scheme for use of Chapter 20 tables (p 3 of 3).

analyst is directed to the appropriate table, he can select the item in the table that most closely approximates the task and conditions being evaluated. However, any tabled HEP may have to be modified according to plant-specific PSFs.

If the table to which the analyst is directed does not list an item that closely approximates the analysis task, he may select an item from some other table that matches the underlying behavioral processes identified in the task analysis. Alternatively, he may rely on judgment or seek other data sources. Some guidance is presented later, in the section entitled, "The Data Tables."

Figure 20-1 is presented here and also at the end of this chapter for the convenience of the analyst.

A Talk-Through of the Search Scheme

The search scheme in Figure 20-1 represents an iterative process, and the analyst may enter the figure at any point in the logic. The ellipses represent reference points, the hexagons represent decision nodes, and the rectangles represent action items.

To illustrate the use of the search scheme, we will enter at the "Start" ellipse and proceed through a hypothetical, complete HRA of the type described in NUREG/CR-2254. Every table will be considered in the following sequence. This talk-through is, of course, generic. To illustrate application of the search scheme for a specific sample HRA, see the first example problem in Chapter 21.

(1) ABNORMAL EVENT? This is the first decision node after "Start." Generally, the abnormal events of major interest in a HRA for a PRA are loss-of-coolant accidents (LOCAs) and transients. If addressing a LOCA or transient, follow the YES path.

(2) SCREENING REQUIRED? As described in Chapter 5, this is the next decision node on the YES path. Screening involves the assignment of very high failure probabilities to each human task. If the very high HEPs do not have a material effect on the system analysis, the task(s) may be dropped from further consideration. The decision as to whether screening is required will be made in conjunction with the system analysts. Assume YES.

(3) Screening values may be obtained for diagnostic performance and for subsequent rule-based actions (RBAs), using Tables 20-1 and 20-2.

(4) SENSITIVITY ANALYSIS OR END? For some purposes, the analysis will end with a screening analysis, or it may be followed by a sensitivity analysis (SA). For either of these cases, follow the YES path. The "Go to SA" ellipse transfers the analyst to the bottom of page 3 of the figure, where he may perform a sensitivity analysis or exit from the flowchart. If postscreening HRA is required, follow the NO path. Assume NO.

(5) NOMINAL DIAGNOSIS REQUIRED? The nominal model for diagnostic performance lists HEPs that are more realistic than the HEPs in the screening model. In most PRAs, the nominal HEPs for diagnostic performance are of interest. Assume YES.

(6) The HEPs for the nominal diagnosis model are listed in Table 20-3 and are used to estimate the probability of control room (CR) personnel failing to properly diagnose one or more abnormal events within the time constraints given by the system analysts.

(7) Table 20-4 lists the CR staffing assumptions as a function of time after recognition of an abnormal event. These assumptions enable the analyst to consider the effects of personnel interaction in modifying the nominal HEPs for postevent activities (e.g., rule-based actions).

(8) RULE-BASED ACTIONS? Usually, RBAs will be evaluated in an HRA. Assume YES and go to the RBA ellipse.

(9) TYPE OF ERROR? This decision node does not have a YES/NO division. The section of the flowchart branching from this decision node and reuniting at the PSF ellipse encompasses all the rule-based tasks usually addressed in an HRA. Tables 20-5 through 20-14 list the HEPs for all the rule-based tasks specified by the action rectangles in this section. The analyst will follow the appropriate path through this section for each rule-based task being evaluated. In many HRAs, all the paths will be used. We will assume that this is the case for this HRA. All the paths flowing from the TYPE OR ERROR? hexagon will be considered before going to the "PSF" ellipse to adjust the nominal HEPs for relevant PSFs. We will address errors of omission first.

(9A) WRITTEN MATERIALS? This decision node applies to whether written materials are mandated for the task. Written materials include formal procedures, ad hoc procedures, and oral instructions that are written down by the recipient as he receives them.

- If YES, Tables 20-5, 20-6, and 20-7 list the HEPs for the preparation of written materials, for the initiation of the task and for the misuse of procedures, and for the omission of procedural items when using written materials. (Note that Table 20-5 includes errors of commission as well as errors of omission, but for convenience is placed only in the OMISSION path from the TYPE OF ERROR? hexagon.)

- If NO, the worker is relying on memory. Table 20-6 provides the HEPs for initiation of the task and Table 20-8 the HEPs in carrying out oral instructions as a function of the number of items to be remembered.

- Returning to the TYPE OF ERROR? hexagon, we will now consider errors of commission.

(9B) INTERFACE TYPE? Displays, controls (including switches for motor-operated valves [MOVs]), and locally operated valves are the three types of man-machine interfaces studied in HRAs.

- For some frequently practiced tasks, the analyst may judge that the probabilities of errors of commission are negligible. See the fourth example in Chapter 21.

- If DISPLAYS, the following tables list the HEPs for selection of displays (20-9), for reading and recording quantitative information from displays (20-10), and for noting the general state of displays (20-12).

- If CONTROLS or MOVs, Table 20-12 lists HEPs for selection and use of switches, connectors, and other manual controls.

- If LOCALLY OPERATED VALVES, Table 20-13 lists HEPs for selecting these valves, and Table 20-14 lists HEPs for recognizing that a valve is not fully open or closed because it sticks.

(10) Transfer to the "PSF" ellipse on page 2 of Figure 20-1. These rectangles list the PSFs that should be considered when evaluating the HEPs for RBAs. The nominal HEPs in any table may not accurately represent a plant-specific situation. Depending on the quality of PSFs observed, the nominal HEP may be raised or lowered by the analyst.

(10A) Table 20-15 indicates the modifiers to be applied to HEPs for changing or restoring the normal states of safety-related components as a function of the tagging level in use. No modification of HEPs is required if the plant uses the usual Level 2 tagging system.

(10B) Table 20-16 lists modifiers to be applied to HEPs for different stress levels under which a task is to be performed, according to the experience level of the personnel on duty. If a task will be performed under different levels of stress at different times, or if different experience levels of personnel will be on duty at different times, the HRA event trees must represent such fractionation, as described in Chapter 5.

(10C) The "Other PSFs" rectangle is a reminder to consider the many other PSFs mentioned in the Handbook that are not listed in the tables. In addition, almost always there are plant-specific PSFs that the analyst will observe in the course of his site visits, which should be included at this point, using judgment to estimate their effects.

(10D) Tables 20-17, 20-18, and 20-19 present equations and tabled HEPs to be applied to the nominal HEPs to allow for the effects of different levels of dependence that may be assessed between tasks performed by one person or for the effects of dependence between people working jointly. (Table 20-4 provides initial estimates of dependence among CR personnel in carrying out procedures after an abnormal event.)

(11) At this stage, the analyst following the HRA sequence shown in Figure 5-6 is ready to perform his first cut at quantifying the total-failure term, $Pr[F_T]$, for each HRA event tree. It is at this point in a PRA that certain human error terms may be dropped from further consideration if, as determined by the system analysts, they have no material impact on the system failure events of interest.

(12) UCBs NEEDED? If point estimates of HEPs without any UCBs are adequate, follow the NO path. Usually, the YES path will be followed:

- Table 20-20 provides guidelines for assigning UCBs (or EFs) to individual HEPs in the analysis. The upper and lower UCBs may be used as one form of SA, as described in Chapter 7.

- Table 20-21 provides UCBs for conditional HEPs based on use of the dependence model.

- Appendix A presents the methodology for propagation of UCBs through an HRA event tree so that UCBs may be assigned to the total-failure term, $Pr[F_T]$, for each HRA event tree. This term plus its UCBs constitute the usual input to the system analyst for inclusion in the overall PRA.

(13) RECOVERY FACTORS? Usually recovery factors (RF) will be considered at this point in the HRA. Assume YES. Transfer to the top of page 3 of the search scheme to the "Recovery from Deviant Conditions" ellipse.

(14) CHECKING of ANOTHER'S WORK? The recovery factor from any deviant condition under normal operating conditions may depend on the direct checking of someone's work (the YES path) or on inspections of plant indications of deviant conditions. In an HRA, both paths are generally followed. We will begin with the YES path.

(15) The YES path leads to Table 20-6, which provides HEPs for the initiation of the task of the checker, and to Table 20-22, which lists HEPs for errors of omission and commission in the checker's task.

(16) The NO path leads to the ANNUNCIATED? hexagon. The recovery cues may be annunciated or unannunciated. We will address both modes.

(16A) If YES, the decision node, TYPE OF ERROR?, leads to one of two tables:

- Table 20-23 presents the Annunciator Response Model listing the HEPs for an operator to initiate intended corrective action to one or more annunciators.

- Table 20-24 lists HEPs for remembering to respond to a steady-on annunciator tile after an interruption or for noticing an important steady-on annunciator tile during the initial audit or subsequent hourly scans.

(16B) If NO, proceed to the decision node, SPECIAL STATUS CHECK OF INDIVIDUAL EQUIPMENT ITEMS? If certain displays are read according to a schedule, or if the operator is otherwise directed to read some display, follow the YES path to the "RBA" ellipse on page 1 of the flowchart. If there is no specific requirement to check the status of individual equipment items, that is, the checking is more of a general inspection, the NO path leads to four tables:

- Table 20-6 lists the HEP for initiation of a scheduled checking or inspection function.

- Table 20-25 lists HEPs for detecting deviant unannunciated indications on different types of displays during the initial audit and on subsequent hourly scans.

- Table 20-26 modifies the HEPs from Table 20-25 when more than one (up to 5) displays are presenting deviant indications.

- Table 20-27 lists HEPs for failure of the basic walk-around inspection to detect unannunciated deviant indications of equipment within 30 days.

(17) At this point, having considered all important recovery factors, the analyst will proceed to the "PSF" ellipse to consider modifications of the recovery HEPs by relevant PSFs. After the PSFs have been considered, follow the NO path from the RECOVERY FACTORS? decision node at the bottom of page 1 of the flowchart and proceed to the "SA" ellipse on page 3.

(18) SENSITIVITY ANALYSIS REQUIRED? The last thing done in a complete HRA is an SA, although it may be done at other times in the HRA also. The SA is important since it provides a means of ascertaining whether different assumptions or estimates result in materially different effects in the overall PRA. Assume YES.

(18A) As indicated in the rectangle, the analyst may use SA to modify any assumptions or HEPs, following the procedure described in Chapters 5 and 7. He may then reenter the search scheme at any point to assess changes resulting from these modifications. Reentry will take him back to the "PSF" ellipse on page 2 of the flowchart and to the recalculation of the end-failure term, $Pr[F_T]$, using new values.

(18B) The search scheme will always take the analyst back to the SENSITIVITY ANALYSIS REQUIRED? decision node on page 3 of the flowchart. When sufficient SA has been accomplished for purposes of the PRA, the NO path from this decision node leads to the "END" ellipse, signifying the completion of the HRA.

List of Chapter 20 Data Tables

The data tables from Part III that are repeated in this chapter are listed below. Note that at the end of the title of each table, there appears in parentheses the table number in Part III to which the Chapter 20 table corresponds. This reference to Part III table numbers will enable the reader to quickly find background discussion of PSFs that does not appear in Chapter 20. For users familiar with the draft Handbook, Table F-2 in Appendix F provides a cross-index of the table numbers in the revised Chapter 20 with the table numbers from the same chapter in the draft Handbook (Swain and Guttmann, 1980).

Ch. 20 Table No.	Title of Table
20-26	Estimated probabilities of failing to detect at least one of one to five unannunciated deviant displays as a function of the BHEP for detection of a single deviant display during periodic scanning (from Table 11-6)
20-27	Estimated probabilities that the basic walk-around inspection will fail to detect a particular deviant indication of equipment outside the control room within 30 days (from Table 19-4)

The Data Tables

This section presents the 27 data tables extracted from Part III. To facilitate rapid access to these tables, a table designator for each table is shown in large print in the outer upper corner of the page on which the table appears. The table designators are expressed without the chapter prefix (e.g., Table 20-6 is expressed as 6).

Figure 20-2, which precedes the first table, is a quick reference guide to the tables, organized under the seven major headings that are used in the search scheme (Figure 20-1). For convenience, Figure 20-2 also appears as the last page in Chapter 20.

We remind the user that the tables in this chapter do not stand alone. They must be considered in association with the descriptive material in those chapters that include the original versions of the tables. It is not possible to include all of the relevant PSFs in each table; the complete Handbook must be used.

Obviously, the tables cannot list every act or task that could take place in an NPP--only the most frequently observed tasks are listed. When a task is being evaluated for which we have no tabled HEPs, we assign a nominal HEP of .003 as a general error of omission or commission if we judge there is some probability of either type of error. When evaluating abnormal events, we assign a nominal HEP of .001 to those tasks for which the tables or text indicate that the HEP is "negligible" under normal conditions. The nominal HEP of .001 allows for the effects of stress that are associated with abnormal events.

Most of the tables list the EFs or UCBs for the HEPs. For cases in which the EFs or UCBs are not listed, Table 20-20 presents guidelines for estimating them. In the course of an SA, the nominal HEP for some task may change significantly as different assumptions are evaluated. Note that the EFs may change when a nominal HEP is changed; for example, under certain assumptions, some task may have a tabled HEP of, say, .008, with an EF of 3. If the assumptions are modified so that the HEP is doubled (to .016), the EF would change from 3 to 5 (see the second and third items in Table 20-20). Also remember that stress and other PSFs may increase the EFs, as indicated in Table 20-20.

Figure 20-2

- **Screening**
  - Diagnosis 1
  - Rule-Based Actions 2
- **Diagnosis**
  - Nominal Diagnosis 3
  - Postevent CR Staffing 4
- **Errors of Omission**
  - Written Materials Mandated
    - Preparation 5
    - Administrative Control 6
    - Procedural Items 7
  - No Written Materials
    - Administrative Control 6
    - Oral Instruction Items 8
- **Errors of Commission**
  - Displays
    - Display Selection 9
    - Read/Record Quantitative 10
    - Check-Read Quantitative 11
  - Control & MOV Selection & Use 12
  - Locally Operated Valves
    - Valve Selection 13
    - Stuck Valve Detection 14
- **PSFs**
  - Tagging Levels 15
  - Stress/Experience 16
  - Dependence 17 18 19
  - Other PSFs (see text)
- **Uncertainty Bounds**
  - Estimate UCBs 20
  - Conditional HEPs and UCBs 21
- **Recovery Factors**
  - Errors by Checker 22
  - Annunciated Cues 23 24
  - Control Room Scanning 25 26
  - Basic Walk-Around Inspection 27

Figure 20-2 Quick reference guide to Chapter 20 tables.

For record-keeping convenience in an HRA, the left-most column for most of the tables is headed by the word, "Item." In keeping a record of which tabled entries are used in an HRA, reference can be made to a particular table and item number, e.g., T20-1, #1. In some of the tables, e.g., Table 20-8, it is convenient to use small letters to designate separate columns of estimated HEPs. For example, in Table 20-8, Item 1a refers to the HEP of .001 (EF = 3), which is the top listing in the first column of HEPs. Record keeping for an HRA is illustrated in the first case study in Chapter 21.

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Table 20-1 Initial-screening model of estimated HEPs and EFS for diagnosis within time T by control room personnel of abnormal events annunciated closely in time* (from Table 12-2) **1**

Item	T (Minutes** after T_0†)	Median joint HEP for diagnosis of a single or the first event	EF	Item	T (Minutes** after T_0†)	Median joint HEP for diagnosis of the second event††	EF
(1)	1	1.0	--	(7)	1	1.0	--
(2)	10	.5	5	(8)	10	1.0	--
(3)	20	.1	10	(9)	20	.5	5
(4)	30	.01	10	(10)	30	.1	10
				(11)	40	.01	10
(5)	60	.001	10				
				(12)	70	.001	10
(6)	1500 (≈ 1 day)	.0001	30				
				(13)	1510	.0001	30

*"Closely in time" refers to cases in which the annunciation of the second abnormal event occurs while CR personnel are still actively engaged in diagnosing and/or planning responses to cope with the first event. This is situation-specific, but for the initial analysis, use "within 10 minutes" as a working definition of "closely in time."

Note that this model pertains to the CR crew rather than to one individual

**For points between the times shown, the medians and EFs may be chosen from Figure 12-3.

†T_0 is a compelling signal of an abnormal situation and is usually taken as a pattern of annunciators. A probability of 1.0 is assumed for observing that there is some abnormal situation.

††Assign HEP = 1.0 for the diagnosis of the third and subsequent abnormal events annunciated closely in time.

2

Table 20-2 Initial-screening model of estimated HEPs and EFS for rule-based actions by control room personnel after diagnosis of an abnormal event* (from Table 12-3)

Item	Potential Errors	HEP	EF
	Failure to perform rule-based actions correctly when written procedures are available and used:		
(1)	Errors per critical step without recovery factors	.05	10
(2)	Errors per critical step with recovery factors	.025	10
	Failure to perform rule-based actions correctly when written procedures are not available or used:		
(3)	Errors per critical step with or without recovery factors	1.0	--

*Note that this model pertains to the CR crew rather than to one individual.

Table 20-3 Nominal model of estimated HEPs and EFs for diagnosis within time T by control room personnel of abnormal events annunciated closely in time* (from Table 12-4)

Item	T (Minutes** after $T_0^{\dagger}$)	Median joint HEP†† for diagnosis of a single or the first event	EF	Item	T (Minutes** after $T_0^{\dagger}$)	Median joint HEP†† for diagnosis of the second event	EF	Item	T (Minutes** after $T_0^{\dagger}$)	Median joint HEP†† for diagnosis of the third event	EF
(1)	1	1.0	--	(7)	1	1.0	--	(14)	1	1.0	--
(2)	10	.1	10	(8)	10	1.0	--	(15)	10	1.0	--
(3)	20	.01	10	(9)	20	.1	10	(16)	20	1.0	--
(4)	30	.001	10	(10)	30	.01	10	(17)	30	.1	10
				(11)	40	.001	10	(18)	40	.01	10
								(19)	50	.001	10
(5)	60	.0001	30								
				(12)	70	.0001	30				
								(20)	80	.0001	30
(6)	1500	.00001	30								
				(13)	1510	.00001	30				
								(21)	1520	.00001	30

*"Closely in time" refers to cases in which the annunciation of the second abnormal event occurs while the control room personnel are still actively engaged in diagnosing and/or planning the responses to cope with the first event. This is situation-specific, but for the initial analysis, use "within 10 minutes" as a working definition of "closely in time."

Note that this model pertains to the CR crew rather than to one individual.

The nominal model for diagnosis includes the activities listed in Table 12-1 as "perceive," "discriminate," "interpret," "diagnosis," and the first level of "decision-making." The modeling includes those aspects of behavior included in the Annunciator Response Model in Table 20-23; therefore, when the nominal model for diagnosis is used, the annunciator model should not be used for the initial diagnosis. The annunciator model may be used for estimating recovery factors for an incorrect diagnosis.

**For points between the times shown, the medians and EFs may be chosen from Figure 12-4.

†T_0 is a compelling signal of an abnormal situation and is usually taken as a pattern of annunciators. A probability of 1.0 is assumed for observing that there is some abnormal situation.

††Table 12-5 presents some guidelines to use in adjusting or retaining the nominal HEPs presented above.

4

Table 20-4 Number of reactor operators and advisors available to cope with an abnormal event and their related levels of dependence: assumptions for PRA* (from Table 18-2)

Item	Time after recognition** of an abnormal event	Operators or advisors handling reactor unit affected† (a)	Dependence levels with others†† (b)
(1)	0 to 1 minute	on-duty RO	
(2)	at 1 minute	on-duty RO,	
		SRO (assigned SRO <u>or</u> shift supervisor, an SRO)	high with RO
(3)	at 5 minutes	on-duty RO,	
		assigned SRO,	high with RO
		shift supervisor	low to moderate with other operators
		1 or more AOs‡	
(4)	at 15 minutes	on-duty RO,	
		assigned SRO,	high with RO
		shift supervisor	low to moderate with other operators
		shift technical advisor	low to moderate with others for diagnosis & major events; high to complete for detailed operations
		1 or more AOs‡	

*These assumptions are nominal and can be modified for plant- and situation-specific conditions.

**For PRA, "recognition" is usually defined as the response to a compelling signal, such as the alarming of one or more annunciators.

†No credit is given for additional operators or advisors (see text, Chapter 18).

††This column indicates the dependence between each additional person and those already on station. The levels of dependence are assumed to remain constant with time and may be modified in a plant-specific analysis.

‡Availability of other AOs after 5 minutes and related levels of dependence should be estimated on a plant- and situation-specific basis.

5

Table 20-5 Estimated HEP per item (or perceptual unit) in preparation of written material* (from Table 15-2)

Item	Potential Errors	HEP	EF
(1)	Omitting a step or important instruction from a formal or ad hoc procedure** or a tag from a set of tags	.003	5
(2)	Omitting a step or important instruction from written notes taken in response to oral instructions†	Negligible	
(3)	Writing an item incorrectly in a formal or ad hoc procedure or on a tag	.003	5
(4)	Writing an item incorrectly in written notes made in response to oral instructions†	Negligible	

*Except for simple reading and writing errors, errors of providing incomplete or misleading technical information are not addressed in the Handbook.

The estimates are exclusive of recovery factors, which may greatly reduce the nominal HEPs.

**Formal written procedures are those intended for long-time use; ad hoc written procedures are one-of-a-kind, informally prepared procedures for some special purpose.

†A maximum of five items is assumed. If more than five items are to be written down, use .001 (EF = 5) for each item in the list.

6

Table 20-6 Estimated HEPs related to failure of administrative control (from Table 16-1)

Item	Task	HEP	EF
(1)	Carry out a plant policy or scheduled tasks such as periodic tests or maintenance performed weekly, monthly, or at longer intervals	.01	5
(2)	Initiate a scheduled shiftly checking or inspection function*	.001	3
	Use written operations procedures under		
(3)	normal operating conditions	.01	3
(4)	abnormal operating conditions	.005	10
(5)	Use a valve change or restoration list	.01	3
(6)	Use written test or calibration procedures	.05	5
(7)	Use written maintenance procedures	.3	5
(8)	Use a checklist properly**	.5	5

*Assumptions for the periodicity and type of control room scans are discussed in Chapter 11 in the section, "A General Display Scanning Model." Assumptions for the periodicity of the basic walk-around inspection are discussed in Chapter 19 in the section, "Basic Walk-Around Inspection."

**Read a single item, perform the task, check off the item on the list. For any item in which a display reading or other entry must be written, assume correct use of the checklist for that item.

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Table 20-7 Estimated probabilities of errors of omission per item of instruction when use of written procedures is specified* (from Table 15-3)

Item**	Omission of item:	HEP	EF
	When procedures with checkoff provisions are correctly used†:		
(1)	Short list, ≤10 items	.001	3
(2)	Long list, >10 items	.003	3
	When procedures without checkoff provisions are used, or when checkoff provisions are incorrectly used††:		
(3)	Short list, ≤10 items	.003	3
(4)	Long list, >10 items	.01	3
(5)	When written procedures are available and should be used but are not used††	.05‡	5

*The estimates for each item (or perceptual unit) presume zero dependence among the items (or units) and must be modified by using the dependence model when a nonzero level of dependence is assumed.

**The term "item" for this column is the usual designator for tabled entries and does <u>not</u> refer to an item of instruction in a procedure.

†Correct use of checkoff provisions is assumed for items in which written entries such as numerical values are required of the user.

††Table 20-6 lists the estimated probabilities of incorrect use of checkoff provisions and of nonuse of available written procedures.

‡If the task is judged to be "second nature," use the lower uncertainty bound for .05, i.e., use .01 (EF = 5).

8

Table 20-8 Estimated probabilities of errors in recalling oral instruction items not written down* (from Table 15-1)

HEPs as a function of number of items to be remembered**

Item†	Number of Oral Instruction Items or Perceptual Units	Pr[F] to recall item "N," order of recall not important (a) HEP	(a) EF	Pr[F] to recall all items, order of recall not important (b) HEP	(b) EF	Pr[F] to recall all items, order of recall is important (c) HEP	(c) EF
	Oral instructions are detailed:						
(1)	1††	.001	3	.001	3	.001	3
(2)	2	.003	3	.004	3	.006	3
(3)	3	.01	3	.02	5	.03	5
(4)	4	.03	5	.04	5	.1	5
(5)	5	.1	5	.2	5	.4	5
	Oral instructions are general:						
(6)	1††	.001	3	.001	3	.001	3
(7)	2	.006	3	.007	3	.01	3
(8)	3	.02	5	.03	5	.06	5
(9)	4	.06	5	.09	5	.2	5
(10)	5	.2	5	.3	5	.7	5

*It is assumed that if more than five oral instruction items or perceptual units are to be remembered, the recipient will write them down. If oral instructions are written down, use Table 20-5 for errors in preparation of written procedures and Table 20-7 for errors in their use.

**The first column of HEPs (a) is for individual oral instruction items, e.g., the second entry, .003 (item 2a), is the Pr[F] to recall the second of two items, given that one item was recalled, and order is not important. The HEPs in the other columns for two or more oral instruction items are joint HEPs, e.g., the .004 in the second column of HEPs is the Pr[F] to recall both of two items to be remembered, when order is not important. The .006 in the third column of HEPs is the Pr[F] to recall both of two items to be remembered in the order of performance specified. For all columns, the EFs are taken from Table 20-20 as explained in Chapter 15.

†The term "item" for this column is the usual designator for tabled entries and does not refer to an oral instruction item.

††The Pr[F]s in rows 1 and 6 are the same as the Pr[F] to initiate the task.

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Table 20-9 Estimated probabilities of errors in selecting unannunciated displays for quantitative or qualitative readings (from Table 11-2)

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Item	Selection of Wrong Display:	HEP*	EF
(1)	when it is dissimilar to adjacent displays**	Negligible	
(2)	from similar-appearing displays when they are on a panel with clearly drawn mimic lines that include the displays	.0005	10
(3)	from similar-appearing displays that are part of well-delineated functional groups on a panel	.001	3
(4)	from an array of similar-appearing displays identified by labels only	.003	3

*The listed HEPs are independent of recovery factors. In some cases, the content of the quantitative or qualitative indication from an incorrect display may provide immediate feedback of the selection error, and the total error can be assessed as negligible.

**This assumes the operator knows the characteristics of the display for which he is searching.

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Table 20-10 Estimated HEPs for errors of commission in reading and recording quantitative information from unannunciated displays (from Table 11-3)

Item	Display or Task	HEP*	EF
(1)	Analog meter	.003	3
(2)	Digital readout (≤ 4 digits)	.001	3
(3)	Chart recorder	.006	3
(4)	Printing recorder with large number of parameters	.05	5
(5)	Graphs	.01	3
(6)	Values from indicator lamps that are used as quantitative displays	.001	3
(7)	Recognize that an instrument being read is jammed, if there are no indicators to alert the user	.1	5
	Recording task: Number of digits or letters** to be recorded		
(8)	≤ 3	Negligible	-
(9)	> 3	.001 (per symbol)	3
(10)	Simple arithmetic calculations with or without calculators	.01	3
(11)	Detect out-of-range arithmetic calculations	.05	5

*Multiply HEPs by 10 for reading quantitative values under a high level of stress if the design violates a strong populational stereotype; e.g., a horizontal analog meter in which values increase from right to left.

**In this case, "letters" refer to those that convey no meaning. Groups of letters such as MOV do convey meaning, and the recording HEP is considered to be negligible.

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Table 20-11 Estimated HEPs for errors of commission in check-reading displays* (from Table 11-4)

Item	Display or Task	HEP	EF
(1)	Digital indicators (these must be read - there is no true check-reading function for digital displays)	.001	3
	Analog meters:		
(2)	with easily seen limit marks	.001	3
(3)	with difficult-to-see limit marks, such as scribe lines	.002	3
(4)	without limit marks	.003	3
	Analog-type chart recorders:		
(5)	with limit marks	.002	3
(6)	without limit marks	.006	3
(7)	Confirming a status change on a status lamp	Negligible**	
(8)	Misinterpreting the indication on the indicator lamps	Negligible†	

*"Check-reading" means reference to a display merely to see if the indication is within allowable limits; no quantitative reading is taken. The check-reading may be done from memory or a written checklist may be used. The HEPs apply to displays that are checked individually for some specific purpose, such as a scheduled requirement, or in response to some developing situation involving that display.

**If operator must hold a switch in a spring-loaded position until a status lamp lights, use HEP = .003 (EF = 3), from Table 20-12, item 10.

†For levels of stress higher than optimal, use .001 (EF = 3).

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Table 20-12 Estimated probabilities of errors of commission in operating manual controls* (from Table 13-3)

Item	Potential Errors	HEP	EF
(1)	Inadvertent activation of a control	see text, Ch. 13	
	Select wrong control on a panel from an array of similar-appearing controls**:		
(2)	identified by labels only	.003	3
(3)	arranged in well-delineated functional groups	.001	3
(4)	which are part of a well-defined mimic layout	.0005	10
	Turn rotary control in wrong direction (for two-position switches, see item 8):		
(5)	when there is no violation of populational stereotypes	.0005	10
(6)	when design violates a strong populational stereotype and operating conditions are normal	.05	5
(7)	when design violates a strong populational stereotype and operation is under high stress	.5	5
(8)	Turn a two-position switch in wrong direction or leave it in the wrong setting	†	
(9)	Set a rotary control to an incorrect setting (for two-position switches, see item 8)	.001	10††
(10)	Failure to complete change of state of a component if switch must be held until change is completed	.003	3
	Select wrong circuit breaker in a group of circuit breakers**:		
(11)	densely grouped and identified by labels only	.005	3
(12)	in which the PSFs are more favorable (see Ch. 13)	.003	3
(13)	Improperly mate a connector (this includes failures to seat connectors completely and failure to test locking features of connectors for engagement)	.003	3

*The HEPs are for errors of commission only and do not include any errors of decision as to which controls to activate.

**If controls or circuit breakers are to be restored and are tagged, adjust the tabled HEPs according to Table 20-15.

†Divide HEPs for rotary controls (items 5-7) by 5 (use same EFs).

††This error is a function of the clarity with which indicator position can be determined: designs of control knobs and their position indications vary greatly. For plant-specific analyses, an EF of 3 may be used.

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Table 20-13 Estimated HEPs for selection errors for locally operated valves (from Table 14-1)

Item	Potential Errors	HEP	EF
	Making an error of selection in changing or restoring a locally operated valve when the valve to be manipulated is		
(1)	Clearly and unambiguously labeled, set apart from valves that are similar in <u>all</u> of the following: size and shape, state, and presence of tags*	.001	3
(2)	Clearly and unambiguously labeled, part of a group of two or more valves that are similar in <u>one</u> of the following: size and shape, state, or presence of tags*	.003	3
(3)	Unclearly or ambiguously labeled, set apart from valves that are similar in <u>all</u> of the following: size and shape, state, and presence of tags*	.005	3
(4)	Unclearly or ambiguously labeled, part of a group of two or more valves that are similar in <u>one</u> of the following: size and shape, state, or presence of tags*	.008	3
(5)	Unclearly or ambiguously labeled, part of a group of two or more valves that are similar in <u>all</u> of the following: size and shape, state, and presence of tags*	.01	3

*Unless otherwise specified, Level 2 tagging is presumed. If other levels of tagging are assessed, adjust the tabled HEPs according to Table 20-15.

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Table 20-14 Estimated HEPs in detecting stuck locally operated valves (from Table 14-2)

Item	Potential Errors	HEP	EF
	Given that a locally operated valve sticks as it is being changed or restored,* the operator fails to notice the sticking valve, when it has		
(1)	A position indicator** only	.001	3
(2)	A position indicator** and a rising stem	.002	3
(3)	A rising stem but no position indicator**	.005	3
(4)	Neither rising stem nor position indicator**	.01	3

*Equipment reliability specialists have estimated that the probability of a valve's sticking in this manner is approximately .001 per manipulation, with an error factor of 10.

**A position indicator incorporates a scale that indicates the position of the valve relative to a fully opened or fully closed position. A rising stem qualifies as a position indicator if there is a scale associated with it.

Table 20-15 The four levels of tagging or locking systems (from Table 16-2)

Level	Description	Modifications to Nominal HEPs*
1	A specific number of tags is issued for each job Each tag is numbered or otherwise uniquely identified. A record is kept of each tag, and a record of each tag issued is entered in a suspense sheet that indicates the expected time of return of the tag; this suspense sheet is checked each shift by the shift supervisor. An operator is assigned the job of tagging controller as a primary duty. For restoration, the numbers on the removed tags are checked against the item numbers in the records, as a recovery factor for errors of omission or selection. <u>OR</u> The number of keys is carefully restricted and under direct control of the shift supervisor. A signout board is used for the keys. Keys in use are tagged out, and each incoming shift supervisor takes an inventory of the keys.	Use lower UCBs
2	Tags are not accounted for individually--the operator may take an unspecified number and use them as required. In such a case, the number of tags in his possession does not provide any cues as to the number of items remaining to be tagged. For restoration, the record keeping does not provide a thorough checking for errors of omission or selection. If an operator is assigned as tagging controller, it is a collateral duty, or the position is rotated among operators too frequently for them to maintain adequate control tags and records and to retain skill in detecting errors of omission or selection. <u>OR</u> The shift supervisor retains control of the keys and records their issuance but does not use visual aids such as signout boards or tags.	Use nominal HEPs
3	Tags are used, but record keeping is inadequate to provide the shift supervisor with positive knowledge of every item of equipment that should be tagged or restored. No tagging controller is assigned. <u>OR</u> Keys are generally available to users without logging requirements.	Use upper UCBs
4	No tagging system exists. <u>OR</u> No locks and keys are used.	Perform separate analysis

*The nominal HEPs are those in the Handbook that relate to tasks involving the application and removal of tags and, unless otherwise specified, are based on Level 2 tagging.

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Table 20-16 Modifications of estimated HEPs for the effects of stress and experience levels (from Table 18-1)

Item	Stress Level	Modifiers for Nominal HEPs* Skilled** (a)	Novice** (b)
(1)	Very low (Very low task load)	x2	x2
	Optimum (Optimum task load):		
(2)	Step-by-step†	x1	x1
(3)	Dynamic†	x1	x2
	Moderately high (Heavy task load):		
(4)	Step-by-step†	x2	x4
(5)	Dynamic†	x5	x10
	Extremely High (Threat stress)		
(6)	Step-by-step†	x5	x10
(7)	Dynamic† Diagnosis††	.25 (EF = 5)	.50 (EF = 5)
		These are the actual HEPs to use with dynamic tasks or diagnosis--they are NOT modifiers.	

*The nominal HEPs are those in the data tables in Part III and in Chapter 20. Error factors (EFs) are listed in Table 20-20.

**A skilled person is one with 6 months or more experience in the tasks being assessed. A novice is one with less than 6 months or more experience. Both levels have the required licensing or certificates.

†Step-by-step tasks are routine, procedurally guided tasks, such as carrying out written calibration procedures. Dynamic tasks require a higher degree of man-machine interaction, such as decision-making, keeping track of several functions, controlling several functions, or any combination of these. These requirements are the basis of the distinction between step-by-step tasks and dynamic tasks, which are often involved in responding to an abnormal event.

††Diagnosis may be carried out under varying degrees of stress, ranging from optimum to extremely high (threat stress). For threat stress, the HEP of .25 is used to estimate performance of an individual. Ordinarily, more than one person will be involved. Tables 20-1 and 20-3 list joint HEPs based on the number of control room personnel presumed to be involved in the diagnosis of an abnormal event for various times after annunciation of the event, and their presumed dependence levels, as presented in the staffing model in Table 20-4.

Table 20-17 Equations for conditional probabilities of success and failure on Task "N," given success or failure on previous Task "N-1," for different levels of dependence (from Table 10-2)

Level of Dependence	Success Equations	Equation No.	Failure Equations	Equation No.
ZD	$Pr[S_{"N"} \| S_{"N-1"} \| ZD] = n$	(10-9)	$Pr[F_{"N"} \| F_{"N-1"} \| ZD] = N$	(10-14)
LD	$Pr[S_{"N"} \| S_{"N-1"} \| LD] = \frac{1 + 19n}{20}$	(10-10)	$Pr[F_{"N"} \| F_{"N-1"} \| LD] = \frac{1 + 19N}{20}$	(10-15)
MD	$Pr[S_{"N"} \| S_{"N-1"} \| MD] = \frac{1 + 6n}{7}$	(10-11)	$Pr[F_{"N"} \| F_{"N-1"} \| MD] = \frac{1 + 6N}{7}$	(10-16)
HD	$Pr[S_{"N"} \| S_{"N-1"} \| HD] = \frac{1 + n}{2}$	(10-12)	$Pr[F_{"N"} \| F_{"N-1"} \| HD] = \frac{1 + N}{2}$	(10-17)
CD	$Pr[S_{"N"} \| S_{"N-1"} \| CD] = 1.0$	(10-13)	$Pr[F_{"N"} \| F_{"N-1"} \| CD] = 1.0$	(10-18)

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Table 20-18 Conditional probabilities of success or failure for Task "N" for the five levels of dependence, given FAILURE on preceding Task "N-1" (from Table 10-3)

	Task "N" Conditional Probabilities*									
	ZD**		LD		MD		HD		CD	
	S	F	S	F	S	F	S	F	S	F
Item	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
(1)	.75	.25	.71	.29	.64	.36	.37	.63	0	1.0
(2)	.9	.1	.85	.15	.77	.23	.45	.55	0	1.0
(3)	.95	.05	.9	.1	.81	.19	.47	.53	0	1.0
(4)	.99	.01†	.94	.06	.85	.15	.49	.51	0	1.0
(5)	.995	.005	.95	.05	.85	.15	.50	.50	0	1.0
(6)	.999	.001	.95	.05	.86	.14	.50	.50	0	1.0
(7)	.9995	.0005	.95	.05	.86	.14	.50	.50	0	1.0
(8)	.9999	.0001	.95	.05	.86	.14	.50	.50	0	1.0
(9)	.99999	.00001	.95	.05	.86	.14	.50	.50	0	1.0

*All conditional probabilities are rounded. Equations 10-14 through 10-18 (Table 20-17) were used to calculate the values in the F columns. The values in the S columns were obtained by subtraction.

**The conditional probabilities given ZD are the basic probabilities for Task "N."

†For PRA purposes, it is adequate to use CHEPs of .05 (for LD), .15 (for MD), and .5 (for HD) when BHEP $<$ .01.

Table 20-19 Conditional probabilities of success or failure for Task "N" for the five levels of dependence, given SUCCESS on preceding Task "N-1" (from Table 10-4)

	Task "N" Conditional Probabilities*									
	ZD**		LD		MD		HD		CD	
	S	F	S	F	S	F	S	F	S	F
Item	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
(1)	.75	.25	.76	.24	.79	.21	.87	.13	1.0	0
(2)	.9	.1	.9	.1	.91	.09	.95	.05	1.0	0
(3)	.95	.05	.95	.05	.94	.06	.97	.03	1.0	0
(4)	.99	.01	.99	.01	.991	.009	.995	.005	1.0	0
(5)	.995	.005	.995	.005	.996	.004	.997	.003	1.0	0
(6)	.999	.001	.999	.001	.999	.001	.9995	.0005	1.0	0
(7)	.9995	.0005	.9995	.0005	.9996	.0004	.9997	.0003	1.0	0
(8)	.9999	.0001	.9999	.0001	.99991	.00009	.99995	.00005	1.0	0
(9)	.99999	.00001	.99999	.00001	.999991	.000009	.999995	.000005	1.0	0

*All conditional probabilities are rounded. Equations 10-9 through 10-13 (Table 20-17) were used to calculate the values in the S columns. The values in the F columns were obtained by subtraction.

**The conditional probabilities, given ZD, are also the basic probabilities for Task "N."

19

Table 20-20 General guidelines for estimating uncertainty bounds for estimated HEPs* (from Table 7-2)

Item	Task and HEP Guidelines**	EF†
	Task consists of performance of step-by-step procedure†† conducted under routine circumstances (e.g., a test, maintenance, or calibration task); stress level is optimal:	
(1)	Estimated HEP < .001	10
(2)	Estimated HEP .001 to .01	3
(3)	Estimated HEP > .01	5
	Task consists of performance of step-by-step procedure†† but carried out in nonroutine circumstances such as those involving a potential turbine/reactor trip; stress level is moderately high:	
(4)	Estimated HEP < .001	10
(5)	Estimated HEP > .001	5
	Task consists of relatively dynamic†† interplay between operator and system indications, under routine conditions, e.g., increasing or reducing power; stress level is optimal	
(6)	Estimated HEP < .001	10
(7)	Estimated HEP > .001	5
(8)	Task consists of relatively dynamic†† interplay between operator and system indications but carried out in nonroutine circumstances; stress level is moderately high	10
(9)	Any task performed under extremely high stress conditions, e.g., large LOCA; conditions in which the status of ESFs is not perfectly clear; or conditions in which the initial operator responses have proved to be inadequate and now severe time pressure is felt (see Ch. 7 for rationale for EF = 5)	5

*The estimates in this table apply to experienced personnel. The performance of novices is discussed in Chapter 18.

**For UCBs for HEPs based on the dependence model, see Table 20-21.

†The highest upper bound is 1.0.

See Appendix A to calculate the UCBs for $\Pr[F_T]$, the total-failure term of an HRA event tree.

††See Table 20-16 for definitions of step-by-step and dynamic procedures.

Table 20-21 Approximate CHEPs and their UCBs for dependence levels* given FAILURE on the preceding task (from Table 7-3)

Item	Levels of Dependence	BHEPs		
		(a)	(b)	(c)
(1)	ZD**	< .01	.05 (EF=5)	.1 (EF=5)
		(d)	(e)	(f)
		.15 (EF=5)	.2 (EF=5)	.25 (EF=5)

Item	Levels of Dependence	Nominal CHEPs and (Lower to Upper UCBs)†		
		(a)	(b)	(c)
(2)	LD	.05 (.015 to .15)	.1 (.04 to .25)	.15 (.05 to .5)
(3)	MD	.15 (.04 to .5)	.19 (.07 to .53)	.23 (.1 to .55)
(4)	HD	.5 (.25 to 1.0)	.53 (.28 to 1.0)	.55 (.3 to 1.0)
(5)	CD	1.0 (.5 to 1.0)	1.0 (.53 to 1.0)	1.0 (.55 to 1.0)
		(d)	(e)	(f)
(2)	LD	.19 (.05 to .75)	.24 (.06 to 1.0)	.29 (.08 to 1.0)
(3)	MD	.27 (.1 to .75)	.31 (.1 to 1.0)	.36 (.13 to 1.0)
(4)	HD	.58 (.34 to 1.0)	.6 (.36 to 1.0)	.63 (.4 to 1.0)
(5)	CD	1.0 (.58 to 1.0)	1.0 (.6 to 1.0)	1.0 (.63 to 1.0)

*Values are rounded from calculations based on Appendix A. All values are based on skilled personnel (i.e., those with >6 months experience on the tasks being analyzed.

**ZD = BHEP. EFs for BHEPs should be based on Table 20-20.

†Linear interpolation between stated CHEPs (and UCBs) for values of BHEPs between those listed is adequate for most PRA studies.

22

Table 20-22 Estimated probabilities that a checker will fail to detect errors made by others* (from Table 19-1)

Item	Checking Operation	HEP	EF
(1)	Checking routine tasks, checker using written materials (includes over-the-shoulder inspections, verifying position of locally operated valves, switches, circuit breakers, connectors, etc., and checking written lists, tags, or procedures for accuracy)	.1	5
(2)	Same as above, but without written materials	.2	5
(3)	Special short-term, one-of-a-kind checking with alerting factors	.05	5
(4)	Checking that involves active participation, such as special measurements	.01	5
	Given that the position of a locally operated valve is checked (item 1 above), noticing that it is not completely opened or closed:	.5	5
(5)	Position indicator** only	.1	5
(6)	Position indicator** and a rising stem	.5	5
(7)	Neither a position indicator** nor a rising stem	.9	5
(8)	Checking by reader/checker of the task performer in a two-man team, <u>or</u> checking by a <u>second</u> checker, routine task (no credit for more than 2 checkers)	.5	5
(9)	Checking the status of equipment if that status affects one's safety when performing his tasks	.001	5
(10)	An operator checks change or restoration tasks performed by a maintainer	Above HEPs ÷ 2	5

*This table applies to cases during normal operating conditions in which a person is directed to check the work performed by others either as the work is being performed or after its completion.

**A position indicator incorporates a scale that indicates the position of the valve relative to a fully opened or fully closed position. A rising stem qualifies as a position indicator if there is a scale associated with it.

Table 20-23 The Annunciator Response Model: estimated HEPs* for multiple annunciators alarming closely in time** (from Table 11-13)

Item	Number of ANNs	$Pr[F_i]$ for each annunciator (ANN) (or completely dependent set of ANNs) successively addressed by the operator										$\overline{Pr[F_i]}$†
		1	2	3	4	5	6	7	8	9	10	
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
(1)	1	.0001										.0001
(2)	2	.0001	.001									.0006
(3)	3	.0001	.001	.002								.001
(4)	4	.0001	.001	.002	.004							.002
(5)	5	.0001	.001	.002	.004	.008						.003
(6)	6	.0001	.001	.002	.004	.008	.016					.005
(7)	7	.0001	.001	.002	.004	.008	.016	.032				.009
(8)	8	.0001	.001	.002	.004	.008	.016	.032	.064			.02
(9)	9	.0001	.001	.002	.004	.008	.016	.032	.064	.13		.03
(10)	10	.0001	.001	.002	.004	.008	.016	.032	.064	.13	.25	.05
(11)	11-15	$Pr[F_i]$ for each additional ANN beyond 10 = .25										.10
(12)	16-20											.15
(13)	21-40											.20
(14)	>40											.25

*The HEPs are for the failure to initiate some kind of intended corrective action as required. The action carried out may be correct or incorrect and is analyzed using other tables. The HEPs include the effects of stress and should not be increased in consideration of stress effects.

EF of 10 is assigned to each $Pr[F_i]$ or $\overline{Pr[F_i]}$. Based on computer simulation, use of an EF of 10 for $\overline{Pr[F_i]}$ yields approximately correct upper bounds for the 95th percentile. The corresponding lower bounds are too high; they are roughly equivalent to 20th-percentile rather than the usual 5th-percentile bounds. Thus, use of an EF of 10 for the mean $Pr[F_i]$ values provides a conservative estimate since the lower bounds are biased high.

**"Closely in time" refers to cases in which two or more annunciators alarm within several seconds or within a time period such that the operator perceives them as a group of signals to which he must selectively respond.

†$\overline{Pr[F_i]}$ is the expected Pr[F] to initiate action in response to a randomly selected ANN (or completely dependent set of ANNs) in a group of ANNs competing for the operator's attention. It is the arithmetic mean of the $Pr[F_i]$s in a row, with an upper limit of .25.

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Table 20-24 Estimated HEPs for annunciated legend lights*
(from Table 11-12)

Item	Task	HEP	EF
(1)	Respond** to one or more annunciated legend lights	See Table 20-23	
(2)	Resume attention to a legend light within 1 minute after an interruption (sound and blinking cancelled before interruption)	.001	3
(3)	Respond to a legend light if more than 1 minute elapses after an interruption (sound and blinking cancelled before interruption)	.95	5
(4)	Respond to a steady-on legend light during initial audit	.90	5
(5)	Respond to a steady-on legend light during other hourly scans	.95	5

*No written materials are used.

**"Respond" means to initiate some action in response to the indicator whether or not the action is correct. It does not include the initial acts of canceling the sound and the blinking; these are assumed to always occur.

Table 20-25 Estimated probabilities of failure to detect one (of one) unannunciated deviant display* at each scan, when scanned hourly** (from Table 11-7)

Item	Display Type	(Initial Audit) 1	Hourly Scans† 2	3	4	5	6	7	8
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
	Analog meters:								
(1)	with limit marks	.05	.31	.50	.64	.74	.81	.86	.90
(2)	without limit marks	.15	.47	.67	.80	.87	.92	.95	.97
	Analog-type chart recorders:								
(3)	with limit marks	.10	.40	.61	.74	.83	.89	.92	.95
(4)	without limit marks	.30	.58	.75	.85	.91	.94	.97	.98
(5)	Annunciator light no longer annunciating	.9	.95	.95	.95	.95	.95	.95	.95
(6)	Legend light†† other than annunciator light	.98	.98	.98	.98	.98	.98	.98	.98
(7)	Indicator lamp††	.99	.99	.99	.99	.99	.99	.99	.99

*"One display" refers to a single display or a group of completely dependent displays, i.e., a perceptual unit.

**For error factors, refer to Table 20-20.

†Written materials not used.

††These displays are rarely scanned more than once per shift, if at all. Hourly HEPs for each are listed for completeness only.

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Table 20-26 Estimated probabilities of failing to detect at least one* of one to five unannunciated deviant displays as a function of the BHEP for detection of a single deviant display during periodic scanning** (from Table 11-6)

	Number of Deviant Indications				
	1	2	3	4	5
	BHEP	Pr[F] to detect at least one deviant display†			
Item	(a)	(b)	(c)	(d)	(e)
(1)	.99	.985	.98	.975	.97
(2)	.95	.93	.90	.88	.86
(3)	.90	.85	.81	.77	.73
(4)	.80	.72	.65	.58	.52
(5)	.70	.59	.51	.43	.37
(6)	.60	.48	.39	.31	.25
(7)	.50	.37	.28	.21	.16
(8)	.40	.28	.20	.14	.10
(9)	.30	.19	.13	.08	.05
(10)	.20	.12	.07	.04	.03
(11)	.10	.05	.03	.02	.01
(12)	.05	.03	.01	.007	.004
(13)	.01	.005	.003	.001	.001

*To estimate the HEP for failure to detect other concurrent unannunciated deviant displays when one has been detected, use the HEP for the initial audit for those displays that <u>are not</u> functionally related to the display detected (from Table 20-25) and use the annunciator response model for those displays that are functionally related to the display detected (from Table 20-23). The HEPs apply when no written materials are used.

**Except for column (a), the entries above are the complements of the entries in Table 11-5.

†For EFs, refer to Table 20-20.

Table 20-27 Estimated probabilities that the basic walk-around inspection* will fail to detect a particular deviant indication of equipment outside the control room within 30 days** (from Table 19-4)

Item	Number of days between walk-arounds per inspector†	Cumulative Pr[F] within 30 days given one inspection per shift††
(1)	1 (daily walk-around for each inspector)	.52
(2)	2	.25
(3)	3	.05
(4)	4	.003
(5)	5	.0002
(6)	6	.0001
(7)	7 (weekly walk-around for each inspector)	.0001

*See Chapter 19 for the assumptions for the basic walk-around inspection. One of these assumptions is that no written procedure is used; if a written procedure is used for a walk-around, use the tables related to errors of omission and commission for performance of rule-based tasks (Figure 20-1, p 1).

**Three shifts per day are assumed. If not, use the appropriate equations in Chapter 19.

†It is assumed that all inspectors have the same number of days between walk-arounds. For other assumptions, modify the relevant equations in Chapter 19.

††For EFs, use the procedure in Appendix A, or use EF = 10 as an approximation.

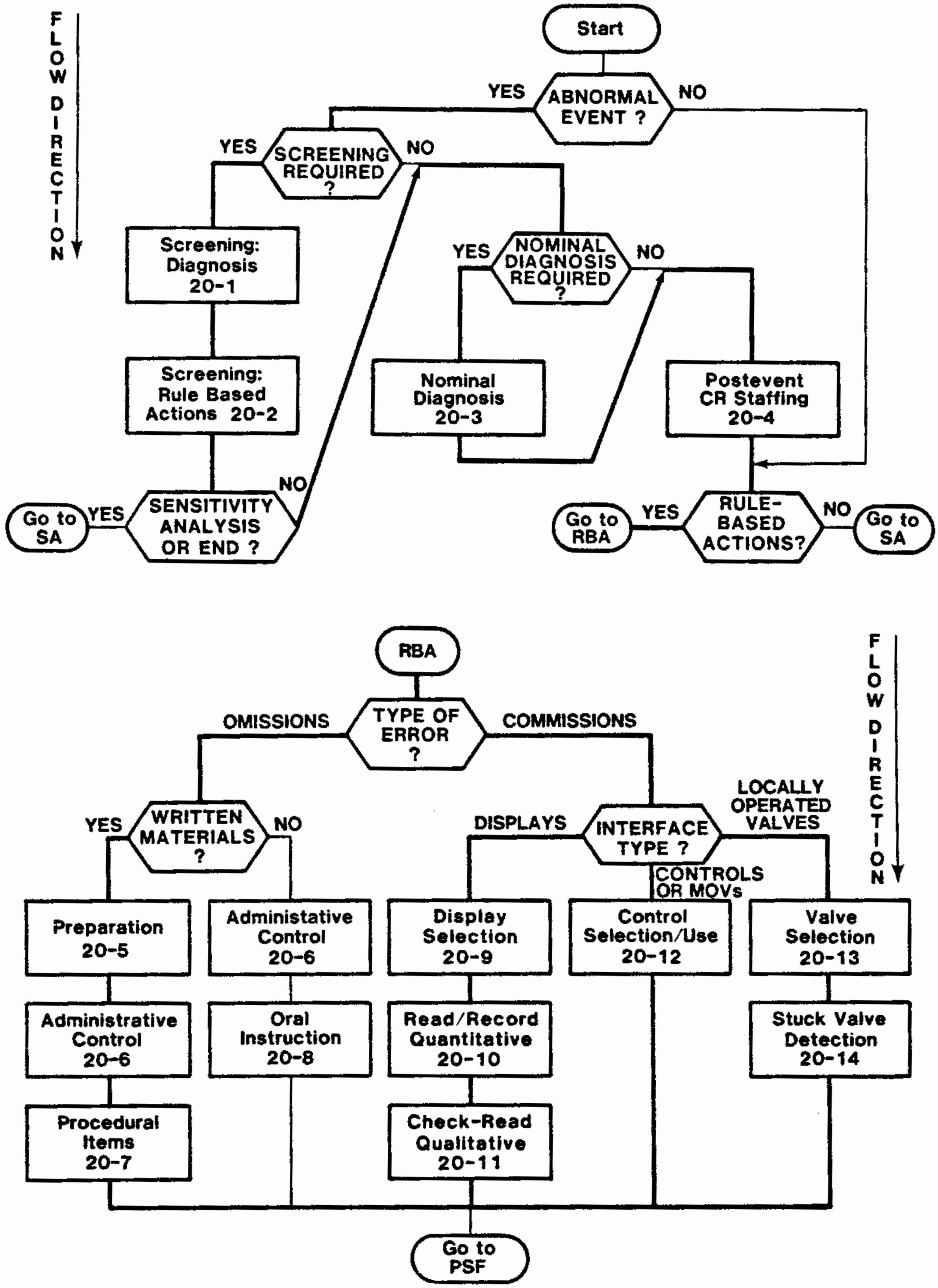


Figure 20-1 Search scheme for use of Chapter 20 tables (p 1 of 3).

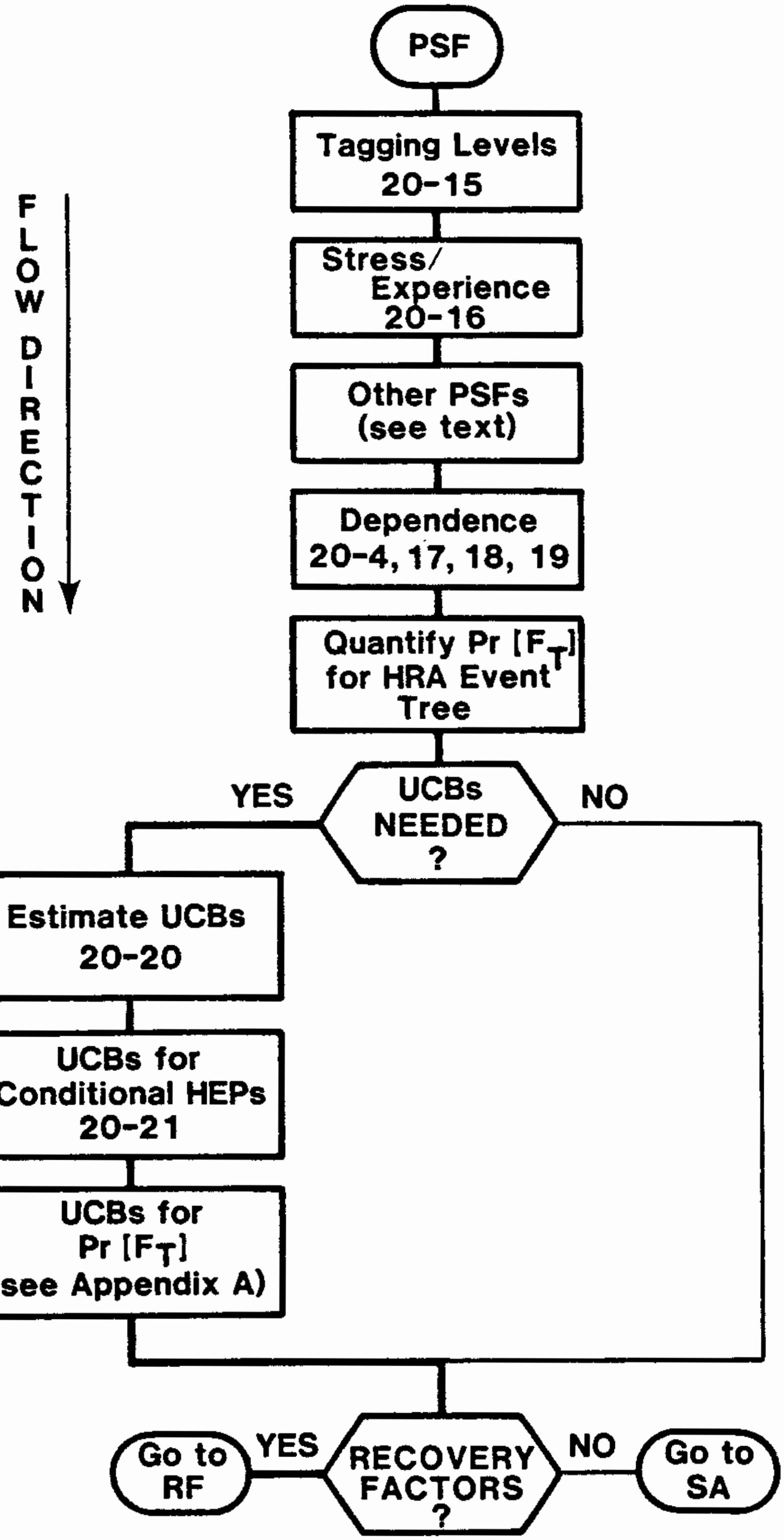


Figure 20-1 Search scheme for use of Chapter 20 tables (p 2 of 3).

Figure 20-1 (3/3)

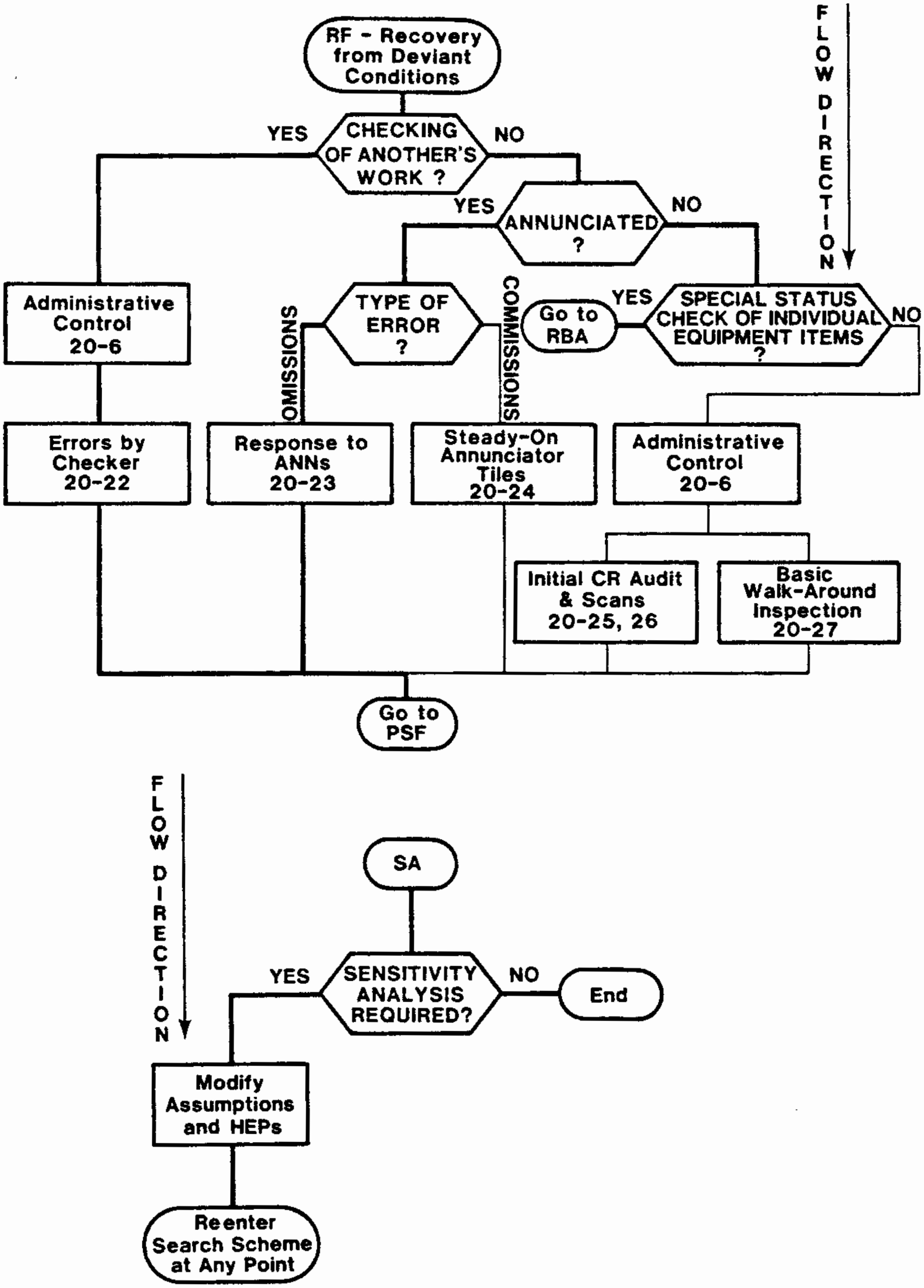


Figure 20-1 Search scheme for use of Chapter 20 tables (p 3 of 3).

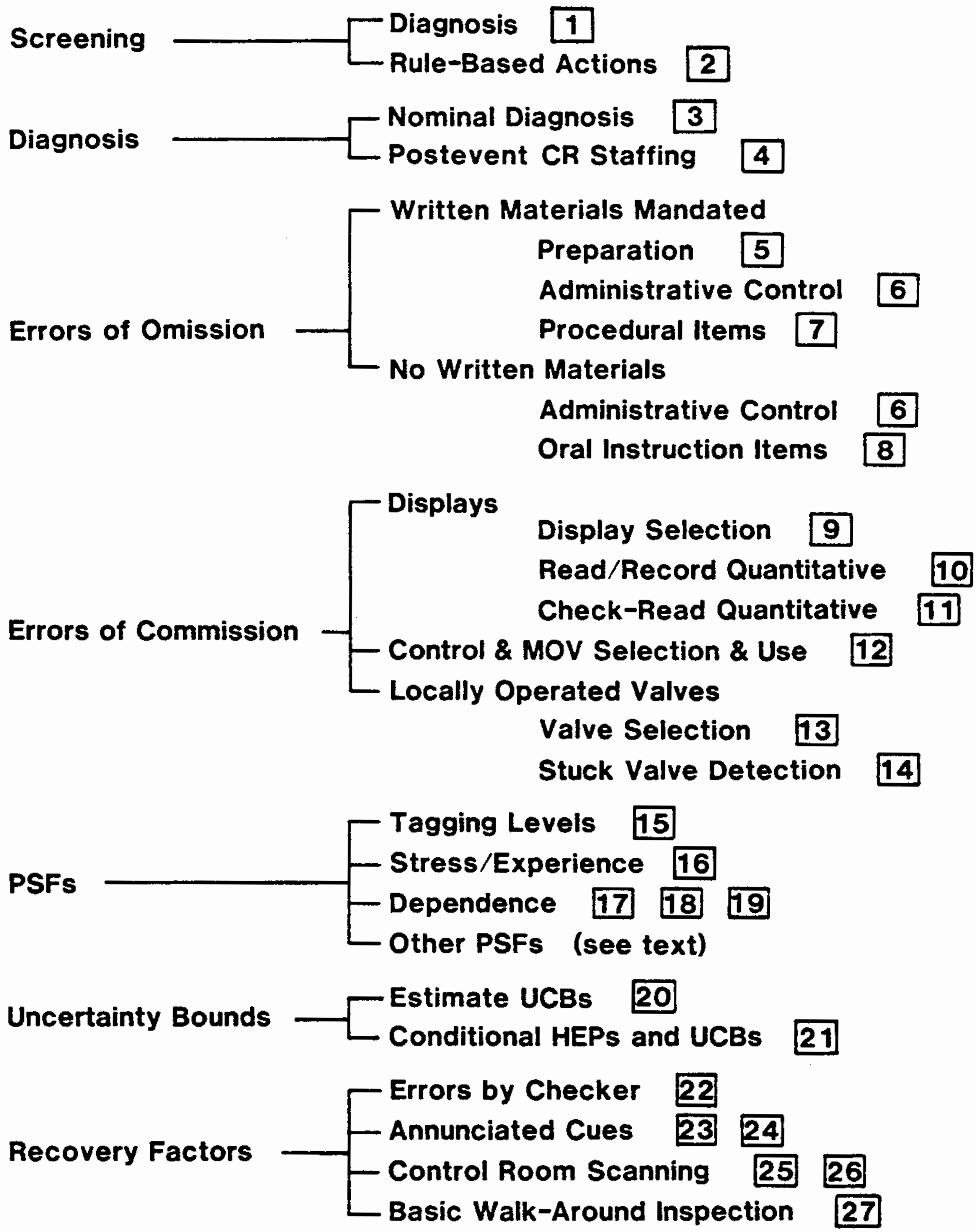


Figure 20-2 Quick reference guide to Chapter 20 tables.

Exercises for THERP

Refer to the system flow diagram and event tree shown on the following pages. We will examine an interfacing system loss of coolant accident (ISLOCA) that begins with internal failure of one of the pairs of check valves that isolate the high-pressure reactor coolant system (RCS) from the interfacing low-pressure residual heat removal (RHR) system. Failure of a pair of these check valves will challenge the RHR discharge relief valves, which lift at 600 psig (valves 1ND31 and 1ND64). However, the relief capacity of these valves (400 gpm) is too small to mitigate the pressure rise in the RHR system. The flanges in the RHR system are not likely to fail as a result of overpressurization, nor are the valves. The most likely location for a large break is the tube-side cylinder of the RHR heat exchangers. If there is a rupture in the RHR system, the scenario will proceed to core damage unless the operators can detect, diagnose, and isolate the break.

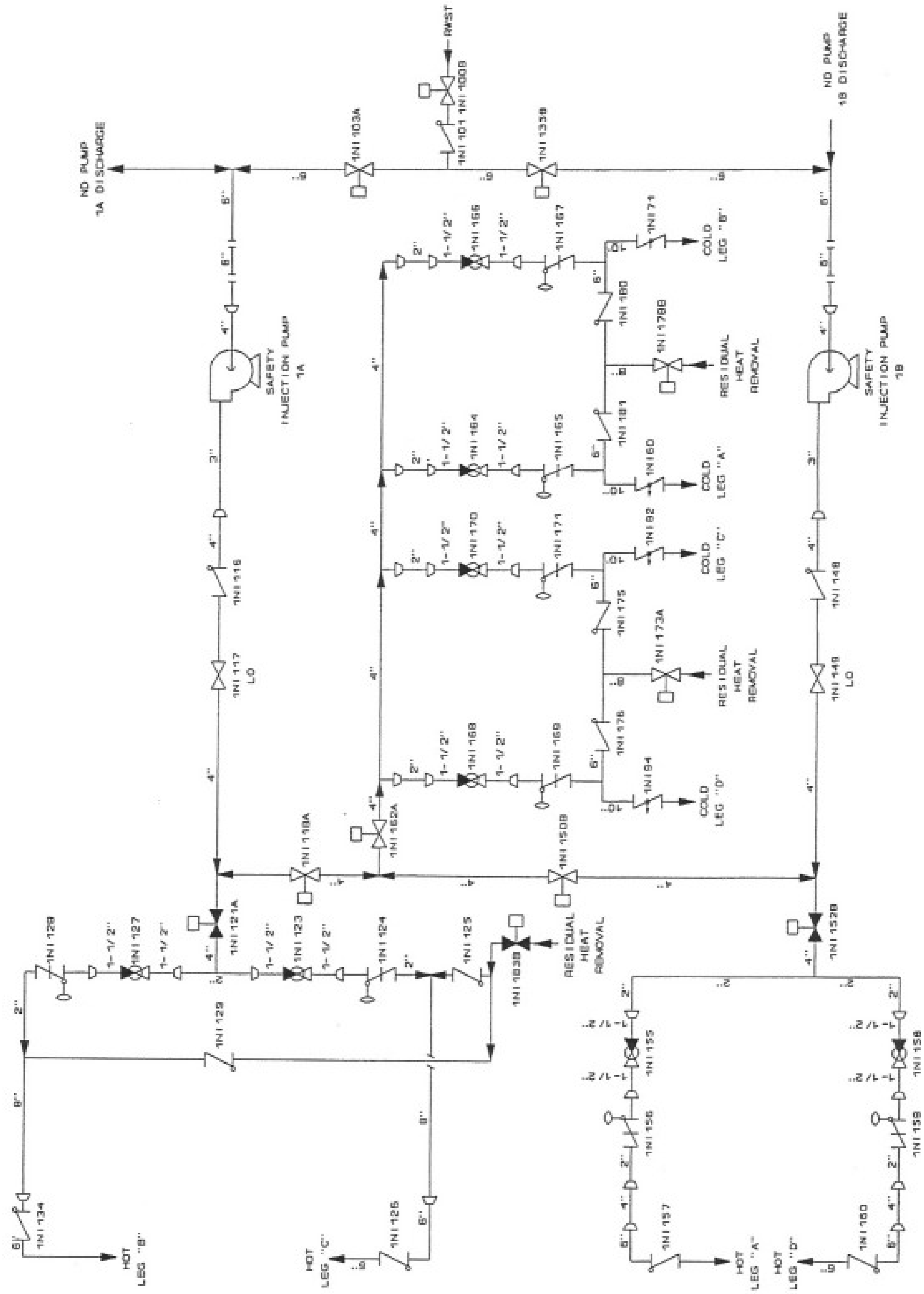
From the event tree, we see there are five human failure events (HFEs) of interest. OP-FTC-2 represents operator failure to isolate the LOCA by closing safety injection isolation motor-operated valves (MOV) 1NI-173A and 1NI-178B, following diagnosis of the ISLOCA. These actions are directed by an Emergency Operating Procedure (EOP) for LOCA Outside Containment, which is entered upon correct diagnosis of the ISLOCA (event DIAG-LOCA).

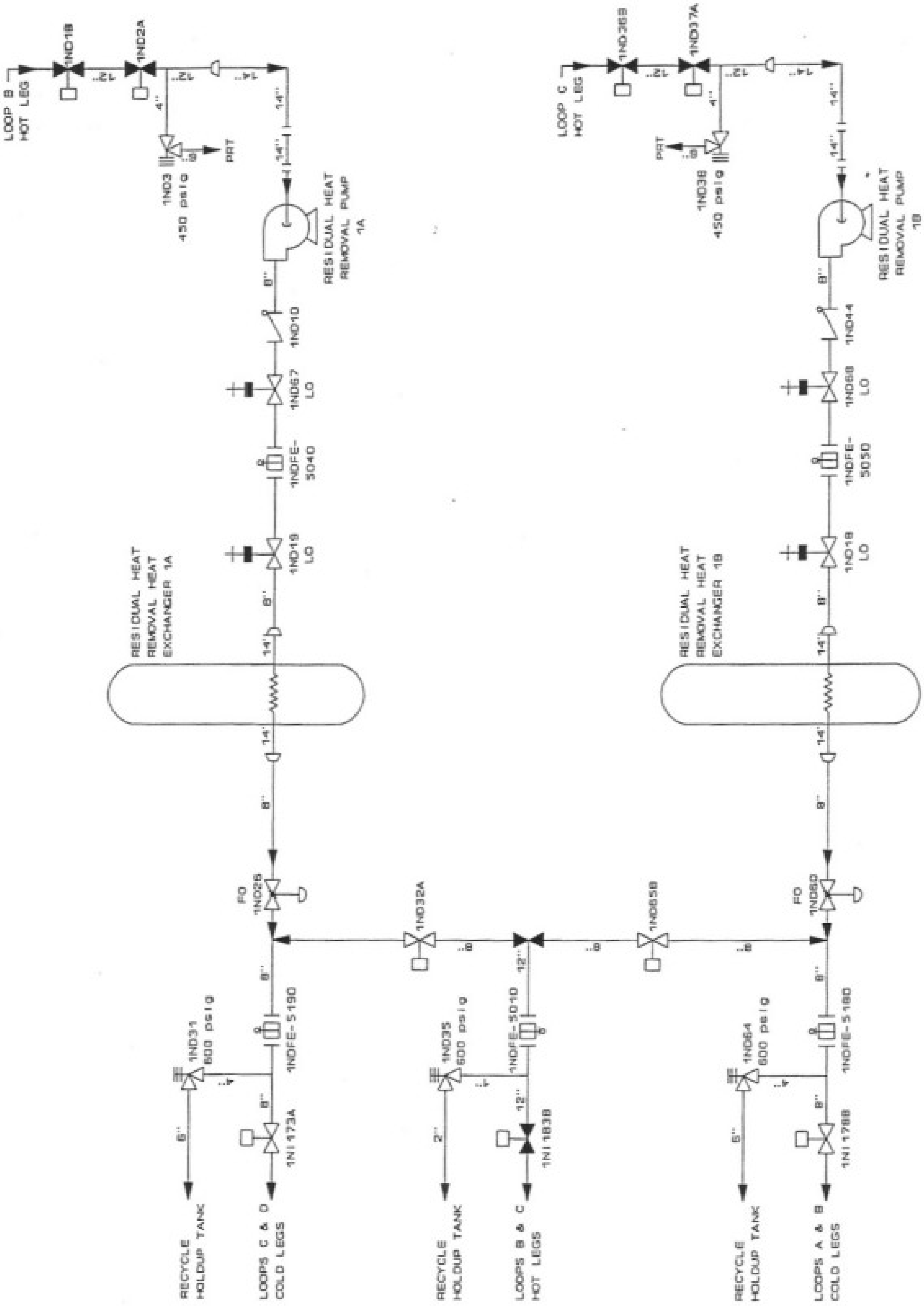
We first illustrate the use of THERP to model event OP-FTC-2. The modeling assumes that the Control Room Supervisor (CRS) is functioning as the procedure reader and that the Reactor Operator (RO) performs actions directed by the procedure. Threat stress is assessed for all subtasks, because this event immediately follows the detection of an auxiliary building high radiation alarm. A moderate level of dependence was assessed between the CRS and RO. The THERP event tree for this action is shown below.

Answer the following questions regarding this THERP analysis.

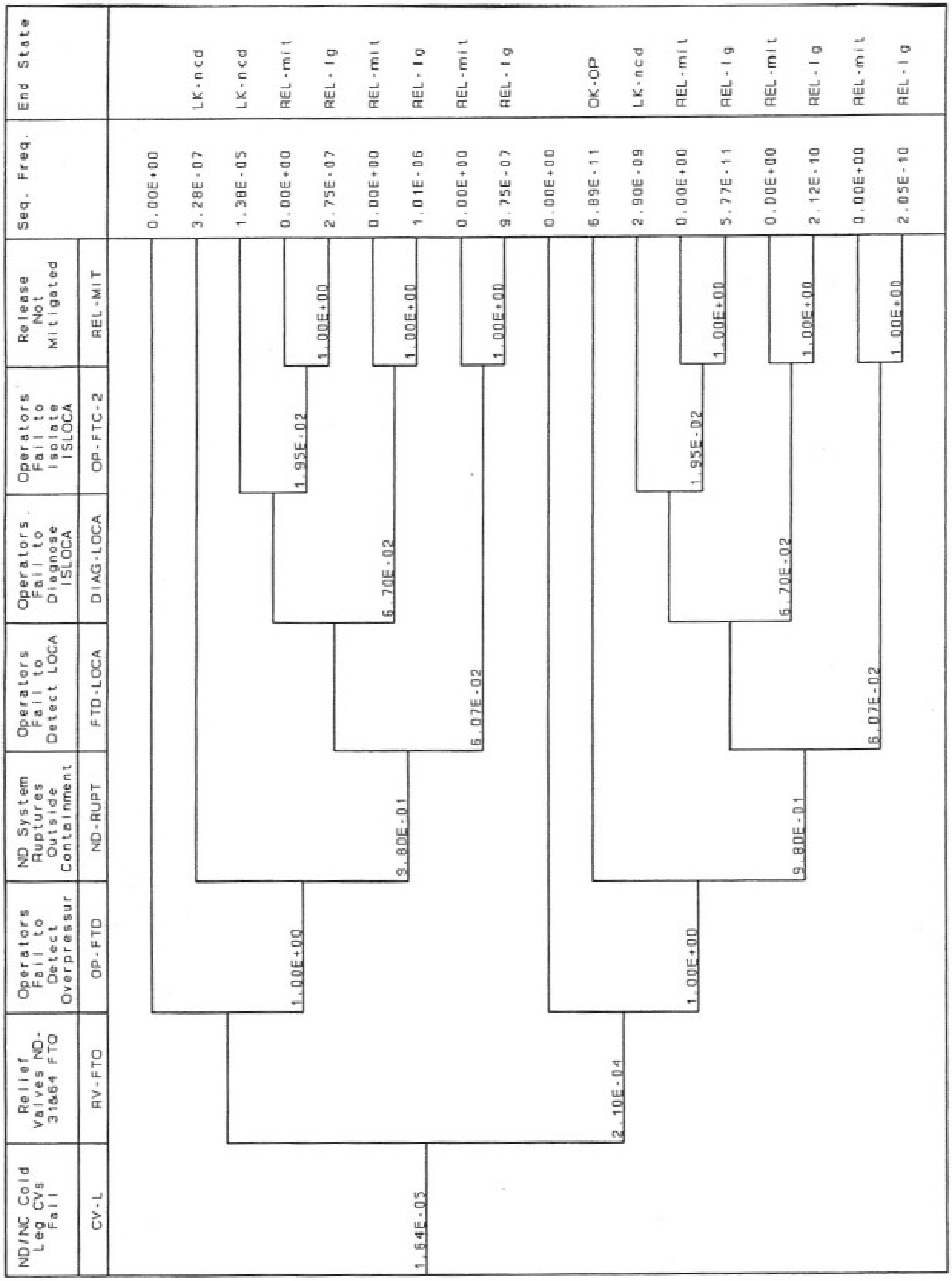
1. What might be a feasible recovery action for subtask A? Why might no credit have been given for this recovery?
2. What recovery actions are modeled in this THERP tree?
3. The nominal HEPs are shown in the THERP tree. Calculate the basic and conditional HEPs, and find the overall HEP for event OP-FTC-2. Assume all actions are step-by-step in nature.

Now consider event DIAG-LOCA in the event tree. The success criterion for this event is correct transition from the Reactor Trip/Safety Injection EOP to the EOP for LOCA Outside Containment. The entry condition is auxiliary building high radiation alarm, EMF-41. Construct and quantify a THERP event tree for failure of the RO to diagnose an ISLOCA according to this criterion.


ND PUMP 1A DISCHARGE
RWST
1NI 103A
1NI 101
1NI 100B
1NI 135B
ND PUMP 1B DISCHARGE
SAFETY INJECTION PUMP 1A
SAFETY INJECTION PUMP 1B
1NI 116
1NI 117 LO
1NI 148
1NI 149 LO
1NI 118A
1NI 162A
1NI 150B
1NI 166
1NI 167
1NI 164
1NI 165
1NI 170
1NI 171
1NI 168
1NI 169
1NI 180
1NI 178B
1NI 181
1NI 175
1NI 173A
1NI 176
COLD LEG "B"
COLD LEG "A"
COLD LEG "C"
COLD LEG "D"
RESIDUAL HEAT REMOVAL
1NI 121A
1NI 127
1NI 128
1NI 123
1NI 124
1NI 125
1NI 183B
1NI 129
1NI 134
1NI 126
HOT LEG "B"
HOT LEG "C"
1NI 152B
1NI 155
1NI 156
1NI 157
1NI 158
1NI 159
1NI 160
HOT LEG "A"
HOT LEG "D"



LOOP B HOT LEG
1ND1B
1ND2A
1ND3 450 psig
PRT
RESIDUAL HEAT REMOVAL PUMP 1A
1ND10
1ND67 LO
1NDFE-5040
1ND19 LO
RESIDUAL HEAT REMOVAL EXCHANGER 1A
FO 1ND26
1ND32A
1ND31 600 psig
1NDFE-5190
1NI173A
RECYCLE HOLDUP TANK
LOOPS C & D COLD LEGS
1ND35 600 psig
1NDFE-5010
1NI183B
LOOPS B & C HOT LEGS
1ND65B
1ND64 600 psig
1NDFE-5160
1NI178B
LOOPS A & B COLD LEGS
FO 1ND60
RESIDUAL HEAT REMOVAL EXCHANGER 1B
1ND18 LO
1NDFE-5050
1ND68 LO
1ND44
RESIDUAL HEAT REMOVAL PUMP 1B
1ND38 450 psig
LOOP C HOT LEG
1ND36B
1ND37A

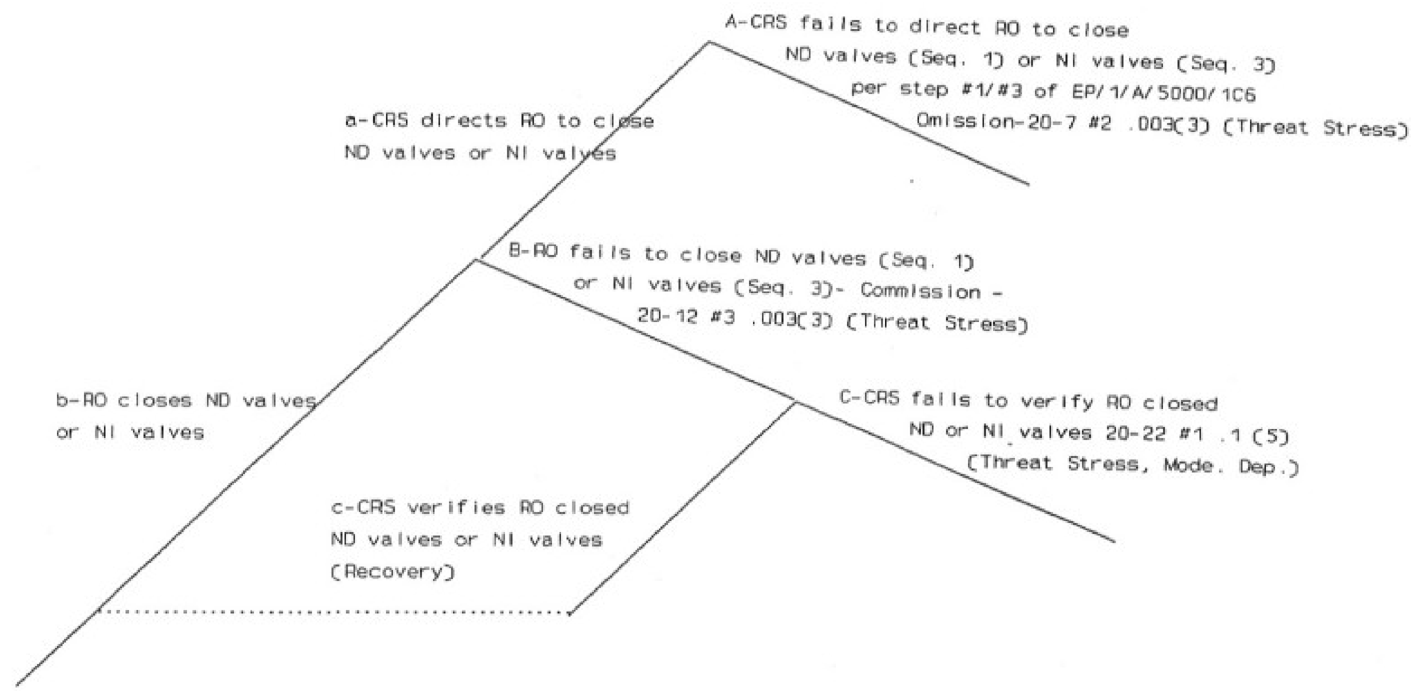


ND/NC Cold Leg CVs Fail
CV-L
Relief Valves ND-31&64 FTO
RV-FTO
Operators Fail to Detect Overpressur
OP-FTD
ND System Ruptures Outside Containment
ND-RUPT
Operators Fail to Detect LOCA
FTD-LOCA
Operators Fail to Diagnose ISLOCA
DIAG-LOCA
Operators Fail to Isolate ISLOCA
OP-FTC-2
Release Not Mitigated
REL-MIT
Seq. Freq.
End State
1.64E-05
2.10E-04
1.00E+00
1.00E+00
9.80E-01
9.80E-01
6.07E-02
6.07E-02
6.70E-02
6.70E-02
1.95E-02
1.95E-02
1.00E+00
1.00E+00
1.00E+00
1.00E+00
1.00E+00
1.00E+00
0.00E+00
3.28E-07 LK-ncd
1.38E-05 LK-ncd
0.00E+00 REL-mit
2.75E-07 REL-lg
0.00E+00 REL-mit
1.01E-06 REL-lg
0.00E+00 REL-mit
9.75E-07 REL-lg
0.00E+00
6.89E-11 OK-OP
2.90E-09 LK-ncd
0.00E+00 REL-mit
5.77E-11 REL-lg
0.00E+00 REL-mit
2.12E-10 REL-lg
0.00E+00 REL-mit
2.05E-10 REL-lg

Sequence 1A, 1B, & 3

OP-FTC-2 (Path 3A & 3B)

** NOTE: Valves ND2A, ND1B, ND36B, & ND37A refer to Sequences 1A & 1B
Valves NI173A & NI178B refer to Sequence 3



HRA Worksheets for At-Power

SPAR HUMAN ERROR WORKSHEET

Plant:__________Initiating Event:________Basic Event :_____________ Event Coder:____________

Basic Event Context:____

Basic Event Description:____

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why?____

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Barely adequate time (≈2/3 x nominal)	10 ☐	
	Nominal time	1 ☐	
	Extra time (between 1 and 2 x nominal and > than 30 min)	0.1 ☐	
	Expansive time (> 2 x nominal and > 30 min)	0.01 ☐	
	Insufficient information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	
	Nominal	1 ☐	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

Reviewer: ____________

Plant:__________Initiating Event:________Basic Event :_____________ Event Coder:____________

Basic Event Context:____

Basic Event Description:____

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = [ ]

C. Calculate the Adjustment Factor <u>IF</u> Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

$$HEP = \frac{NHEP \cdot PSF_{composite}}{NHEP \cdot \left(PSF_{composite} - 1\right) + 1}$$

Diagnosis HEP with Adjustment Factor = [ ]

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = [ ]

Reviewer: ____________

Plant:__________Initiating Event:________Basic Event :_____________ Event Coder:____________

Basic Event Context:____

Basic Event Description:____

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Time available is ≈ the time required	10 ☐	
	Nominal time	1 ☐	
	Time available ≥ 5x the time required	0.1 ☐	
	Time available is ≥ 50x the time required	0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	3 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	5 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	

Reviewer: ____________

Plant:__________Initiating Event:________Basic Event :_____________ Event Coder:____________

Basic Event Context:____

Basic Event Description:____

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = [ ]

C. Calculate the Adjustment Factor <u>IF</u> Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

$$HEP = \frac{NHEP \cdot PSF_{composite}}{NHEP \cdot \left(PSF_{composite} - 1\right) + 1}$$

Action HEP with Adjustment Factor = [ ]

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = [ ]

Reviewer: ____________

Plant:__________Initiating Event:________Basic Event :_____________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP _________ + Action HEP _________ = ☐

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: ________________________

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. If this error is the **4th error in the sequence**, then the dependency is at least **high.**
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (_______ * _______))/ _______ = ☐

Reviewer: ___________

HRA Worksheets for LP/SD

SPAR HUMAN ERROR WORKSHEET

Plant:__________Initiating Event:________Basic Event :_____________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why?______________________________________

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Barely adequate time (≈ 2/3 x nominal)	10 ☐	
	Nominal time	1 ☐	
	Extra time (between 1and 2 x nominal and > 30 min)	0.1 ☐	
	Expansive time > 2 x nominal & > 30 min	0.1 to 0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	
	Nominal	1 ☐	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

Rev 1 (1/20/04)

Reviewer: ___________

Plant:__________Initiating Event:________Basic Event :_____________ Event Coder:____________

Basic Event Context:____

Basic Event Description:____

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = ☐

C. Calculate the Adjustment Factor <u>IF</u> Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

$$HEP = \frac{NHEP \cdot PSF_{composite}}{NHEP \cdot \left(PSF_{composite} - 1\right) + 1}$$

Diagnosis HEP with Adjustment Factor = ☐

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = ☐

Reviewer: ____________

Plant:_________Initiating Event:_______Basic Event :____________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	
	Time available is ≈ the time required	10	☐	
	Nominal time	1	☐	
	Time available ≥ 5x the time required	0.1	☐	
	Time available is ≥ 50x the time required	0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☐	
	High	2	☐	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Complexity	Highly complex	5	☐	
	Moderately complex	2	☐	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Experience/ Training	Low	3	☐	
	Nominal	1	☐	
	High	0.5	☐	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	
	Incomplete	20	☐	
	Available, but poor	5	☐	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	
	Poor	10	☐	
	Nominal	1	☐	
	Good	0.5	☐	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	
	Degraded Fitness	5	☐	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Work Processes	Poor	5	☐	
	Nominal	1	☐	
	Good	0.5	☐	
	Insufficient Information	1	☐	

Reviewer: ___________

Plant:__________Initiating Event:________Basic Event :_____________ Event Coder:____________

Basic Event Context:____

Basic Event Description:____

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = [ ]

C. Calculate the Adjustment Factor <u>IF</u> Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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Final Action HEP = [ ]

Reviewer: ____________

Plant:_________Initiating Event:_______Basic Event :____________ Event Coder:___________

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Basic Event Description:____

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

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Part IV. DEPENDENCY

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Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. If this error is the **4th error in the sequence**, then the dependency is at least **high.**
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$

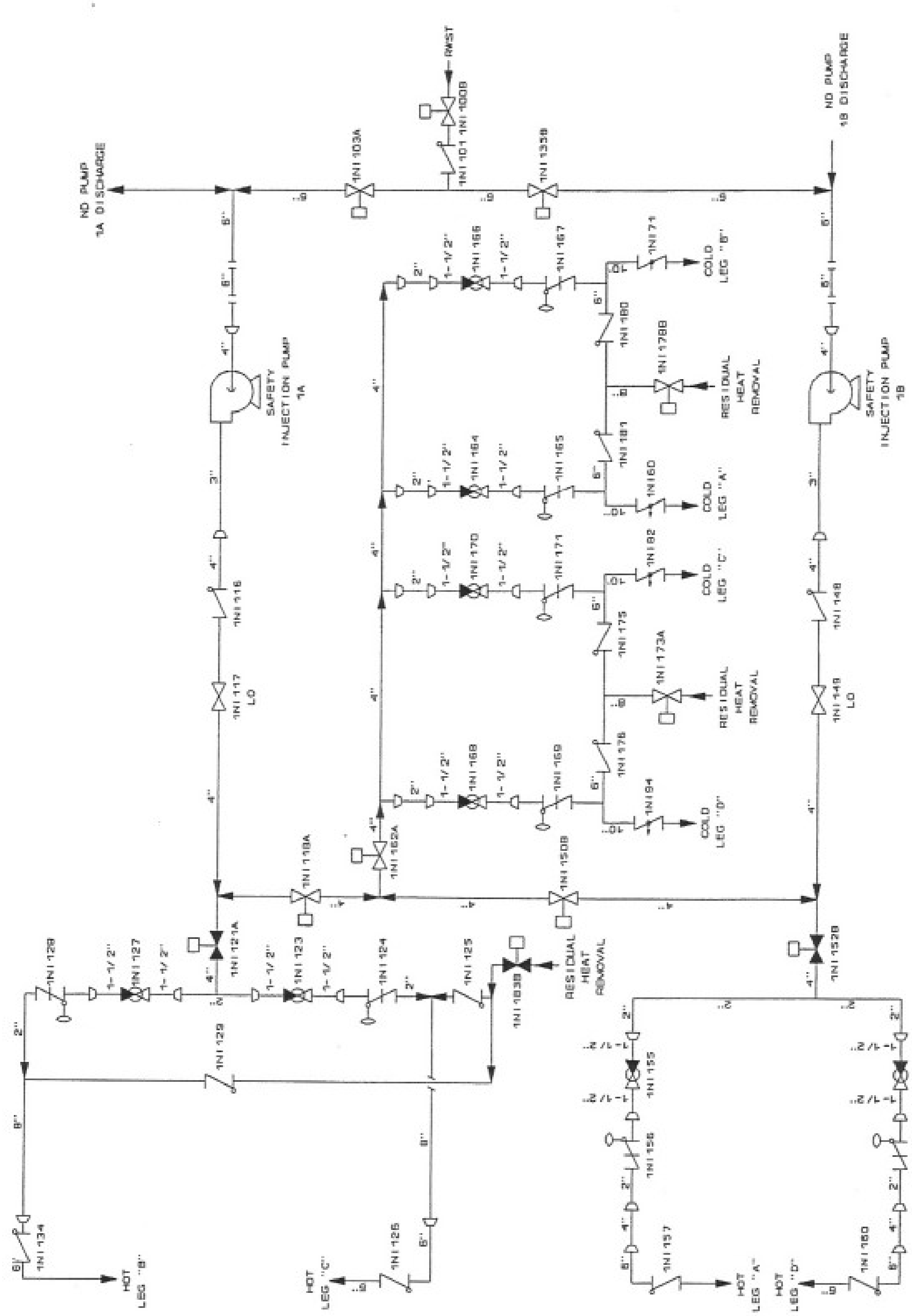
Calculate $P_{w/d}$ using the appropriate values:

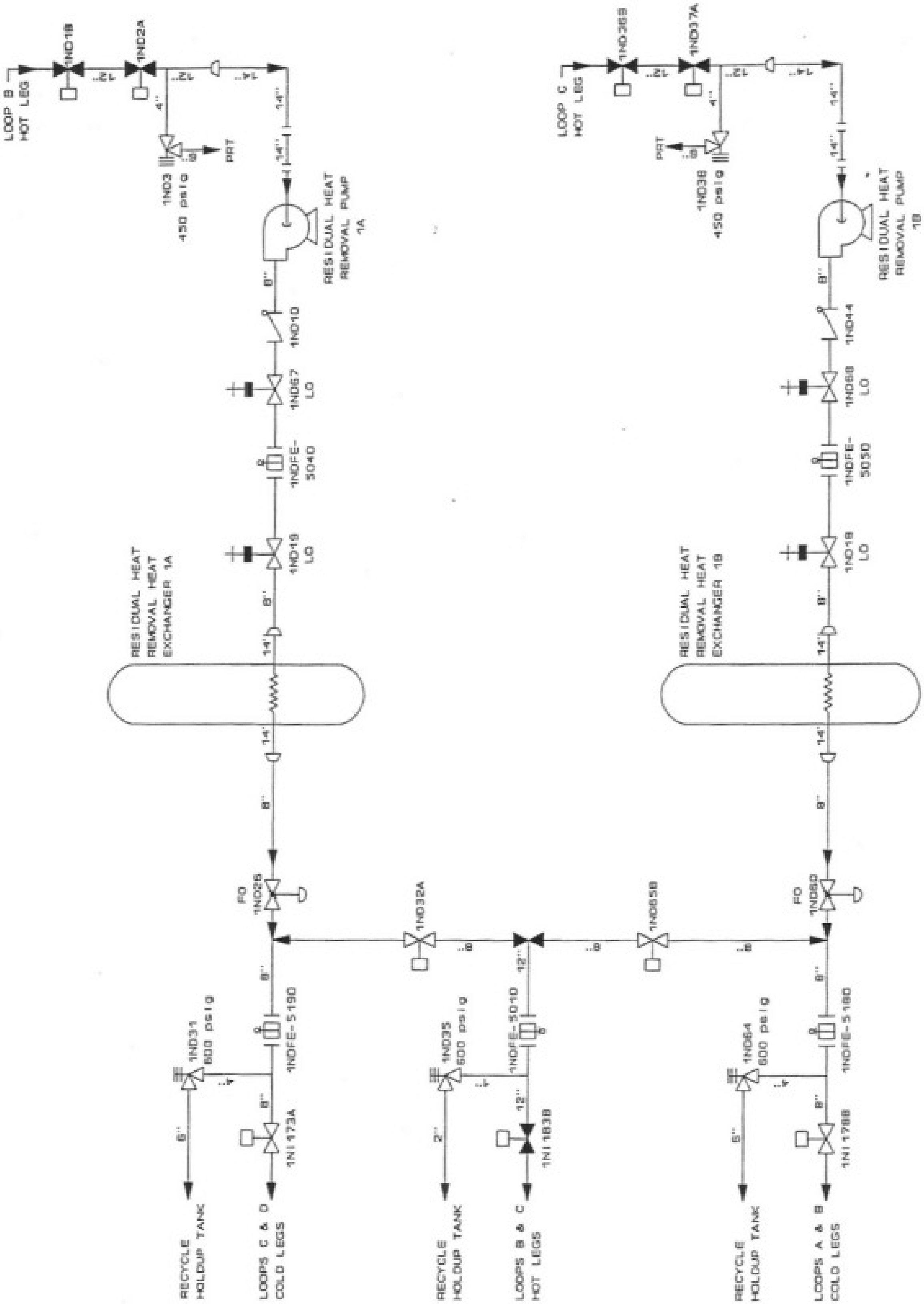
$P_{w/d}$ = (1 + (_______ * _______))/ _______ = ☐

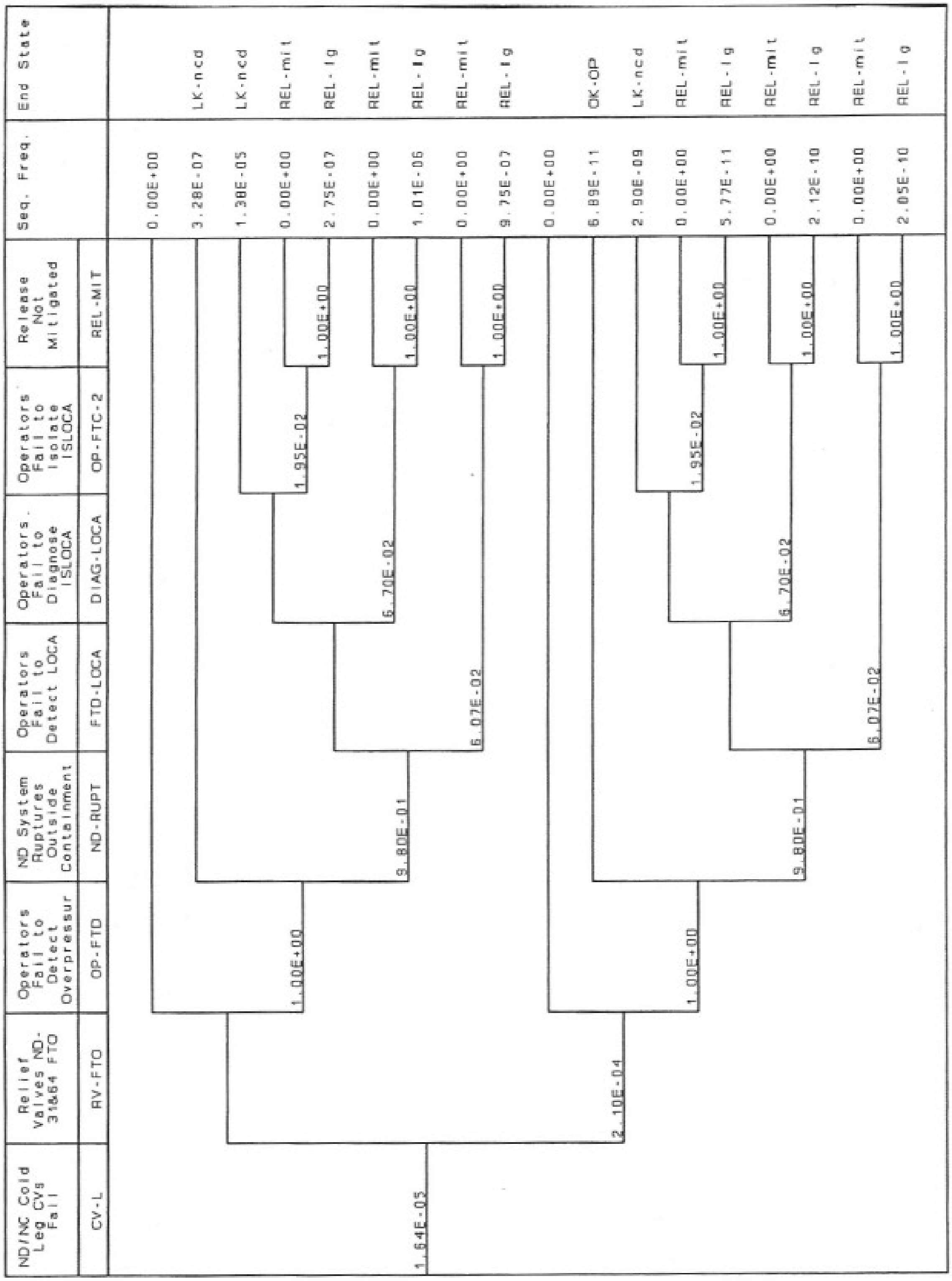
Reviewer: ___________

Exercises for SPAR-H

Requantify events OP-FTC-2 and DIAG-LOCA from the THERP exercise using SPAR-H. Note that task decomposition is not required for SPAR-H, in contrast to the approach of THERP. Assume that the time available from the initiator until the onset of severe core damage is 1.5 hours.


ND PUMP 1A DISCHARGE
ND PUMP 1B DISCHARGE
RWST
SAFETY INJECTION PUMP 1A
SAFETY INJECTION PUMP 1B
RESIDUAL HEAT REMOVAL
COLD LEG "A"
COLD LEG "B"
COLD LEG "C"
COLD LEG "D"
HOT LEG "A"
HOT LEG "B"
HOT LEG "C"
HOT LEG "D"
1NI 103A
1NI 133B
1NI 101
1NI 100B
1NI 117 LO
1NI 116
1NI 149 LO
1NI 148
1NI 118A
1NI 162A
1NI 150B
1NI 121A
1NI 152B
1NI 183B


LOOP B HOT LEG
1ND1B
1ND2A
1ND3
450 psig
PRT
RESIDUAL HEAT REMOVAL PUMP 1A
1ND10
1ND67 LO
1NDFE-5040
1ND19 LO
RESIDUAL HEAT REMOVAL EXCHANGER 1A
FO 1ND26
1ND32A
1ND31 600 psig
1NDFE-5190
1NI173A
RECYCLE HOLDUP TANK
LOOPS C & D COLD LEGS
1ND35 600 psig
1NDFE-5010
1NI183B
RECYCLE HOLDUP TANK
LOOPS B & C HOT LEGS
1ND65B
1ND64 600 psig
1NDFE-5180
1NI178B
RECYCLE HOLDUP TANK
LOOPS A & B COLD LEGS
LOOP C HOT LEG
1ND36B
1ND37A
1ND38
450 psig
PRT
RESIDUAL HEAT REMOVAL PUMP 1B
1ND44
1ND68 LO
1NDFE-5050
1ND18 LO
RESIDUAL HEAT REMOVAL EXCHANGER 1B
FO 1ND60



ND/NC Cold Leg CVs Fail
CV-L
Relief Valves ND-31&64 FTO
RV-FTO
Operators Fail to Detect Overpressur
OP-FTD
ND System Ruptures Outside Containment
ND-RUPT
Operators Fail to Detect LOCA
FTD-LOCA
Operators Fail to Diagnose ISLOCA
DIAG-LOCA
Operators Fail to Isolate ISLOCA
OP-FTC-2
Release Not Mitigated
REL-MIT
Seq. Freq.
End State
1.64E-05
2.10E-04
1.00E+00
1.00E+00
9.80E-01
9.80E-01
6.07E-02
6.07E-02
6.70E-02
6.70E-02
1.95E-02
1.95E-02
1.00E+00
1.00E+00
1.00E+00
1.00E+00
1.00E+00
1.00E+00
0.00E+00
3.28E-07 LK-ncd
1.38E-05 LK-ncd
0.00E+00 REL-mit
2.75E-07 REL-lg
0.00E+00 REL-mit
1.01E-06 REL-lg
0.00E+00 REL-mit
9.75E-07 REL-lg
0.00E+00
6.89E-11 OK-OP
2.90E-09 LK-ncd
0.00E+00 REL-mit
5.77E-11 REL-lg
0.00E+00 REL-mit
2.12E-10 REL-lg
0.00E+00 REL-mit
2.05E-10 REL-lg

Sequence 1A, 1B, & 3

OP-FTC-2 (Path 3A & 3B)

** NOTE: Valves ND2A, ND1B, ND36B, & ND37A refer to Sequences 1A & 1B
Valves NI173A & NI178B refer to Sequence 3