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

Introduction to Human Reliability Analysis (HRA)

NRC-RES Fire PRA Workshop
Module IV
August 5 – 9, 2019
Rockville, MD

Objectives

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

Introduction to HRA Outline

- **What is HRA?**
- Where does HRA fit into PRA?
- What does HRA model?
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- Any final questions?

Human Reliability Analysis (HRA) ….

Is generally defined as:

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

Is developed because:

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

Produces:

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

HRA …. (continued)

- Requires inputs from many sources and technical disciplines, including:
  - Plant information:
    - Design information such as post-initiating event behavior
    - Engineering (e.g., thermal hydraulics and room heat-up calculations)
    - Plant operations (procedures and how they are used)
    - Plant hardware (ergonomics of monitoring and control interfaces, both inside and outside of the main control room)
  - PRA model information:
    - Accident progression following an initiating event
    - Systems and operator actions modeled in response
  - HRA discipline - cognitive and behavioral science
  - Etc., etc., etc.
- Is performed by a multi-disciplinary team

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Overview of PRA Process

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

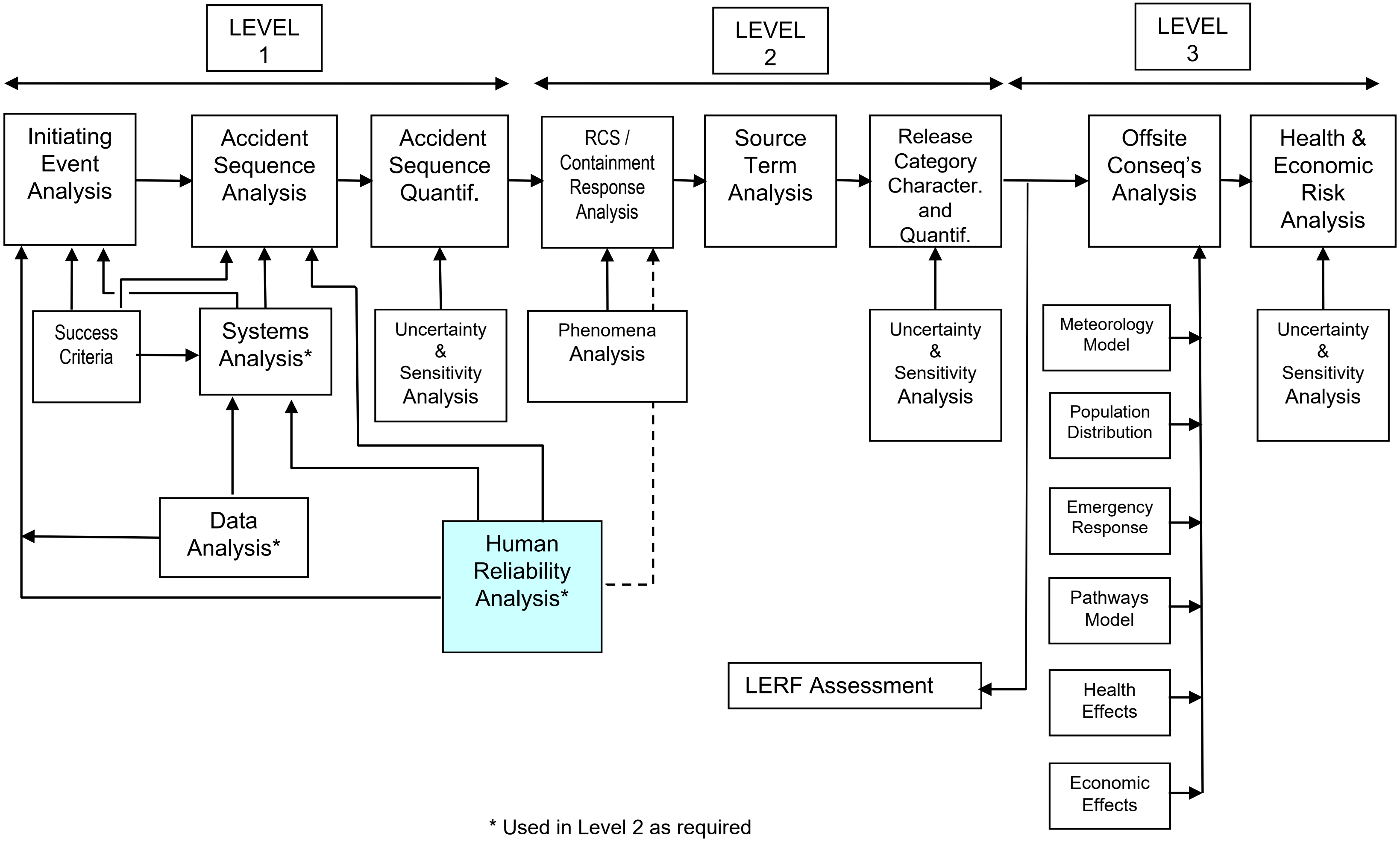
Level	An Assessment of:	Result
1	Plant accident initiators and systems'/operators' response	Core damage frequency and contributors
2	Reactor core melt, and frequency and modes of containment failure	Categorization and frequencies of containment releases
3	Public health consequences	Estimation of public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

PRA Classification

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

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

Principal Steps in PRA



LEVEL 1
LEVEL 2
LEVEL 3
Initiating Event Analysis
Accident Sequence Analysis
Accident Sequence Quantif.
RCS / Containment Response Analysis
Source Term Analysis
Release Category Character. and Quantif.
Offsite Conseq's Analysis
Health & Economic Risk Analysis
Success Criteria
Systems Analysis*
Uncertainty & Sensitivity Analysis
Phenomena Analysis
Uncertainty & Sensitivity Analysis
Meteorology Model
Uncertainty & Sensitivity Analysis
Population Distribution
Data Analysis*
Human Reliability Analysis*
Emergency Response
Pathways Model
LERF Assessment
Health Effects
Economic Effects

* Used in Level 2 as required

Principal Steps in PRA (continued)

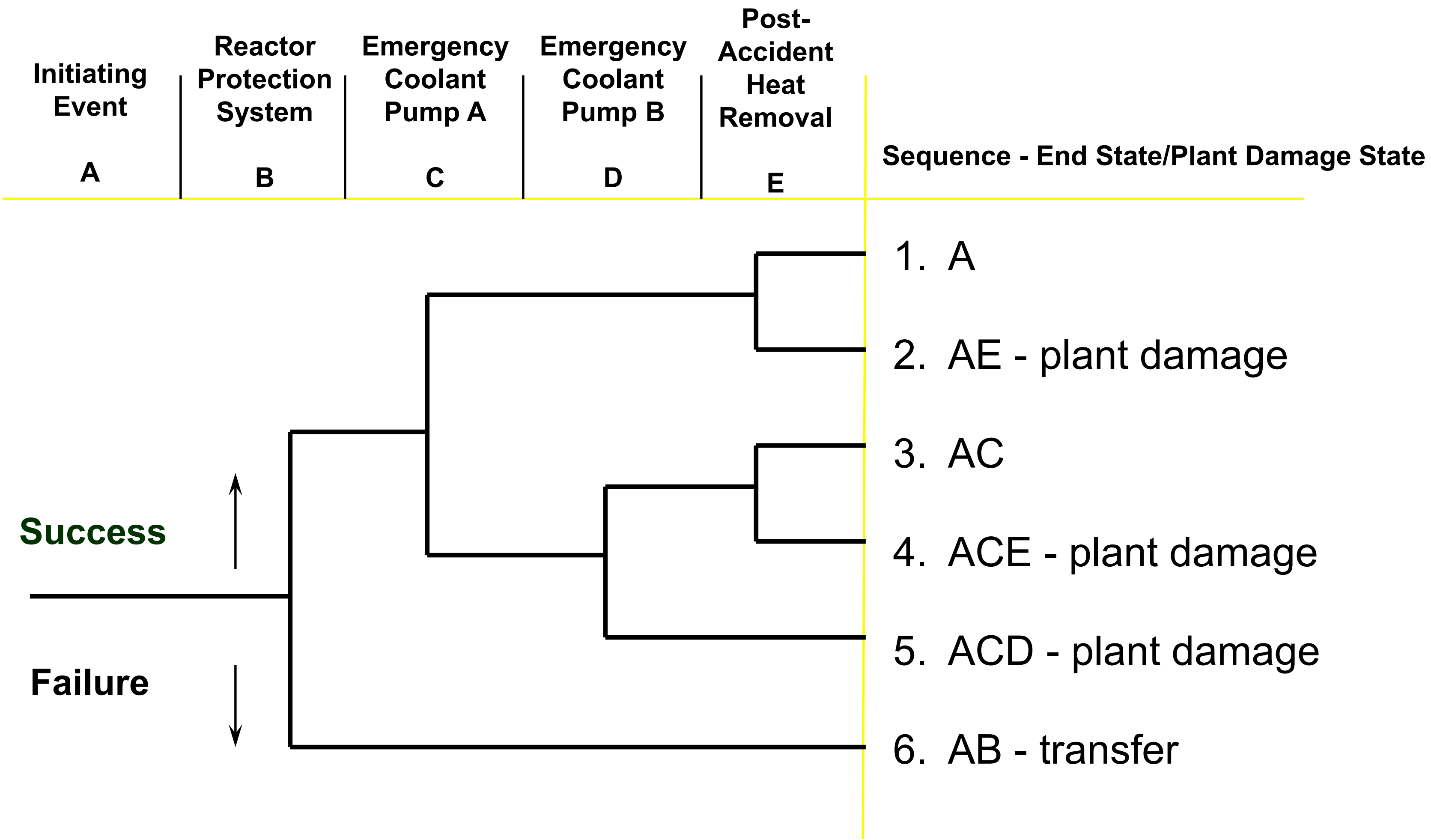
- First, we'll look at how HRA fits into Event Tree (ETs) models.

Human Events in Event Trees

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

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

Simple Event Tree



Initiating Event A

Reactor Protection System B

Emergency Coolant Pump A C

Emergency Coolant Pump B D

Post-Accident Heat Removal E

Sequence - End State/Plant Damage State

Success

Failure

1. A
2. AE - plant damage
3. AC
4. ACE - plant damage
5. ACD - plant damage
6. AB - transfer

System-Level Event Tree Development

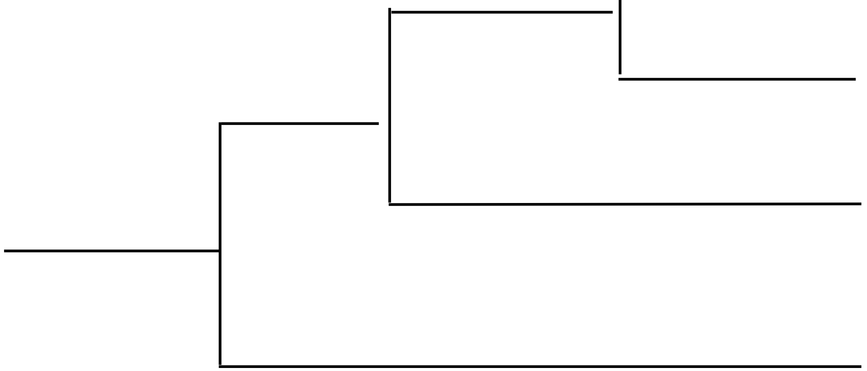
- A system-level event tree consists of an initiating event (one per tree), followed by a number of headings (top events), and sequences of events defined by success or failure of the top events
- Top events represent the systems, components, and/or human actions required to mitigate the initiating event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

System-Level Event Tree Development (continued)

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

Functional Event Tree

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



SEQ #	STATE
1	OK
2	LATE-CD
3	EARLY-CD
4	ATWS

Critical Safety Functions

Example safety functions for core and containment

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

Example BWR Mitigating Systems

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

Example PWR Mitigating Systems

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

System Success Criteria

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

Example Success Criteria

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

What does HRA do with ET information?

For example, the HRA analyst:

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

What does HRA do with ET information? (continued)

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

Principal Steps in PRA (continued)

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

Human Events in Fault Trees

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

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

Human Events in Fault Trees (continued)

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

Specific Failure Modes Modeled for Each Component

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

Typical Component Failure Modes

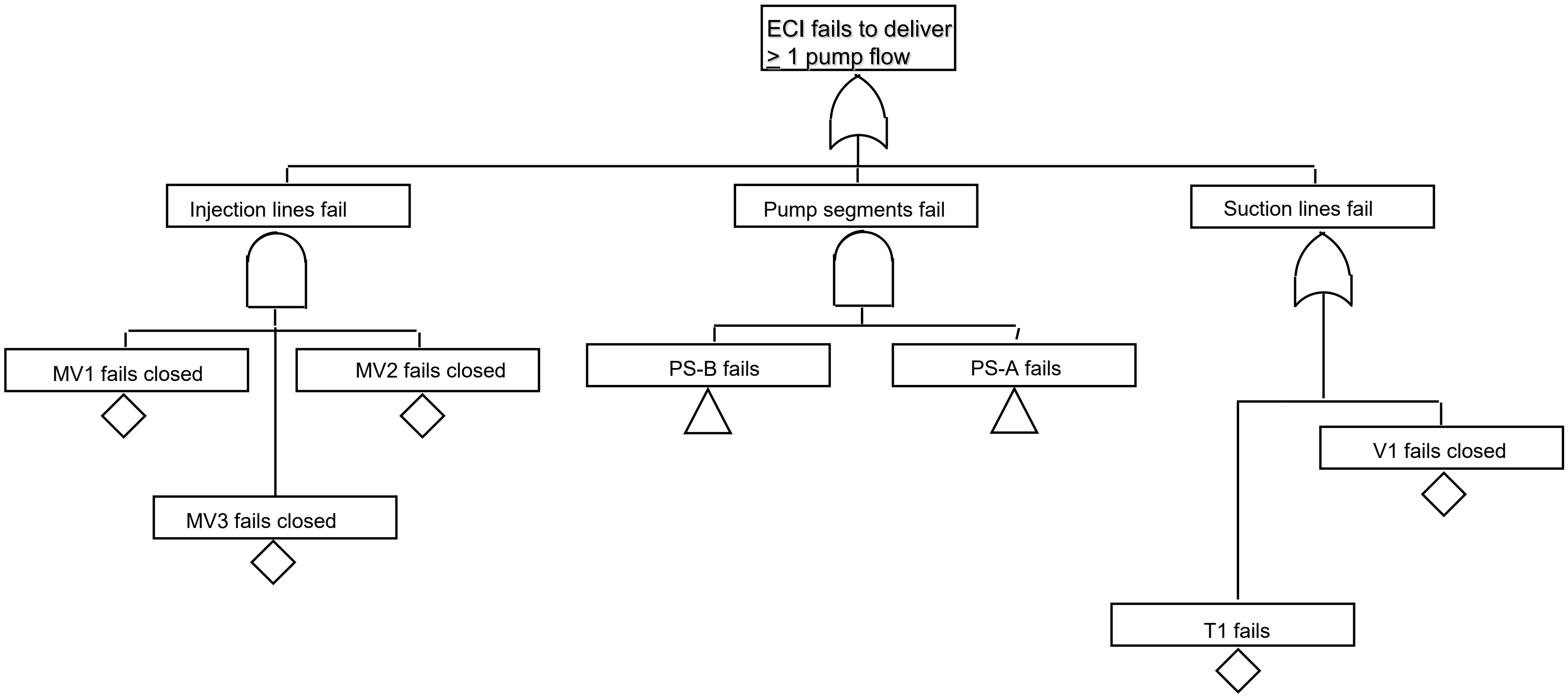
- Active Components
  - Fail to Start*
  - Fail to Run*
  - Fail to Open/Close/Operate*
- Additional “failure mode” is component is unavailable because it is out for test or maintenance

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

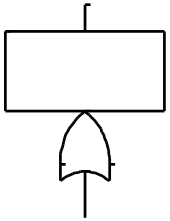
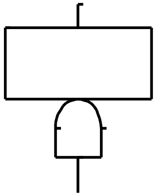
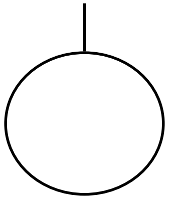
Active Components Require “Support”

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

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



Fault Tree Symbols

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

What does HRA do with FT information?

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

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Human Reliability Analysis

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

Human Reliability Analysis Objectives

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

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

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

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

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

Ref. ASME RA-Sa-2009

Categories of Human Failure Events in PRA

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

Categories of Human Failure Events: Pre-Initiator HFEs

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

Categories of Human Failure Events: Initiating-Event Related

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

Categories Of Human Failure Events: Post-Initiator HFEs

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

Other Classifications of Human Failure Events

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

Other Classifications of HFEs (continued)

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

Other Classifications of HFEs (continued)

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

Other Classifications of HFEs (continued)

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

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What are the keys to performing HRA?

The key is to….

What are the keys to performing HRA?

…understand the problem.

What are the keys to performing HRA?

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

What are the keys …? (continued)

Why do you need to “understand the problem”? (continued)

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

What are the keys …? (continued)

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

What are the keys …? (continued)

- Increasingly, the HRA/PRA recognizes the importance of HRA qualitative analysis.
- More focus on qualitative analysis is appearing in recent or upcoming HRA/PRA guidance, e.g.,
  - Joint EPRI/NRC-RES Fire HRA guidance (NUREG-1921/EPRI 1023001, July 2012)
  - ATHEANA (NUREG-1624, Rev. 1)
  - EPRI's HRA Calculator
- This emphasis is supported or based on recent studies such as:
  - "International HRA Empirical Study – Phase 1 Report" (NUREG/IA-0216, Volume 1, 2009)

What are the keys to performing HRA?

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

What are the keys to performing HRA?

context.

What are the keys to performing HRA?

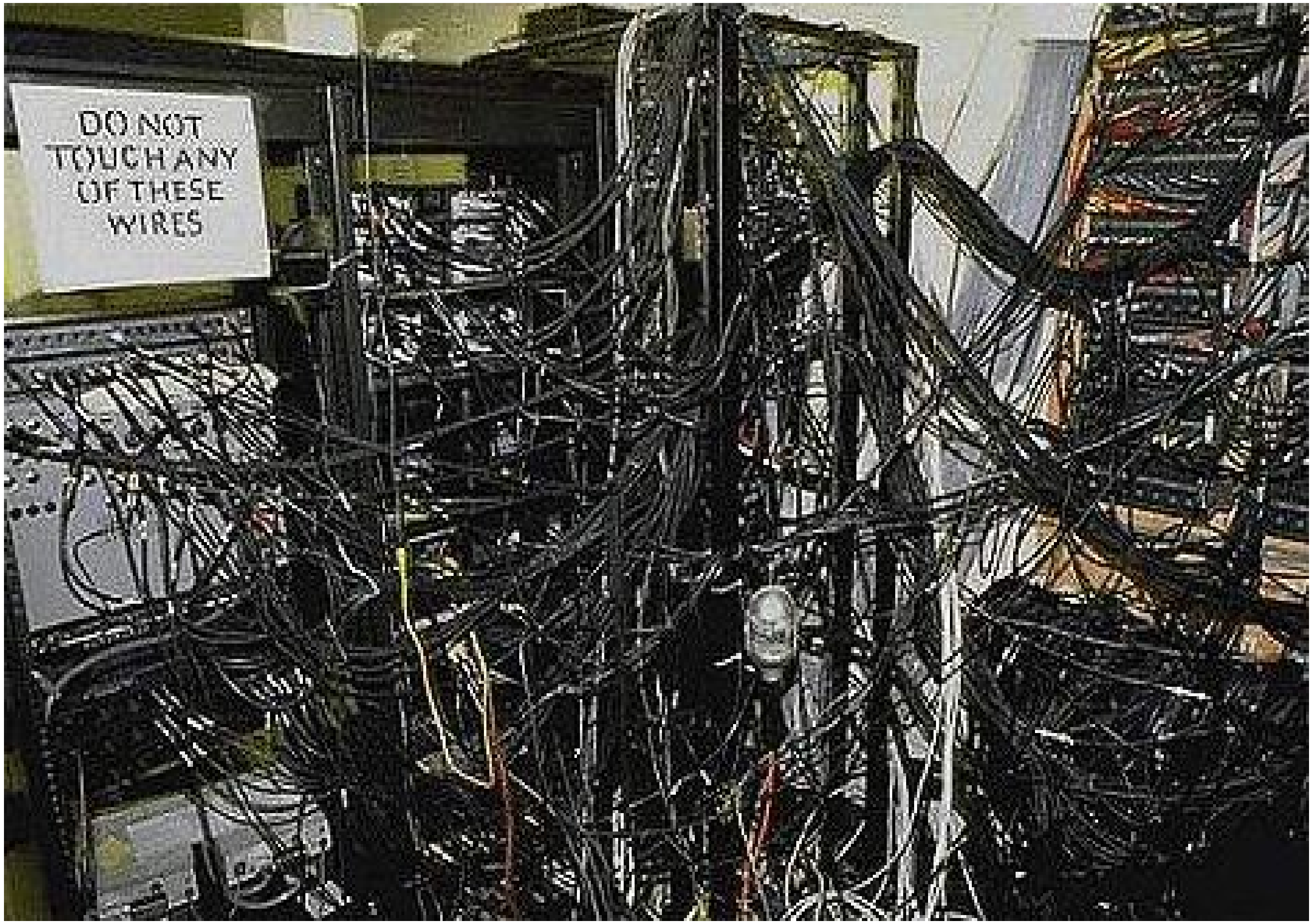
- Context has long been recognized as important, e.g.,
  - SHARP1 (1992) discusses the importance of addressing human interactions for plant-specific and accident sequence-specific scenarios.
- However, a commonly held belief, still evident in popular accounts of incidents and reflected in how some people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

What are the keys …? (continued)

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

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

What are the keys to performing HRA?



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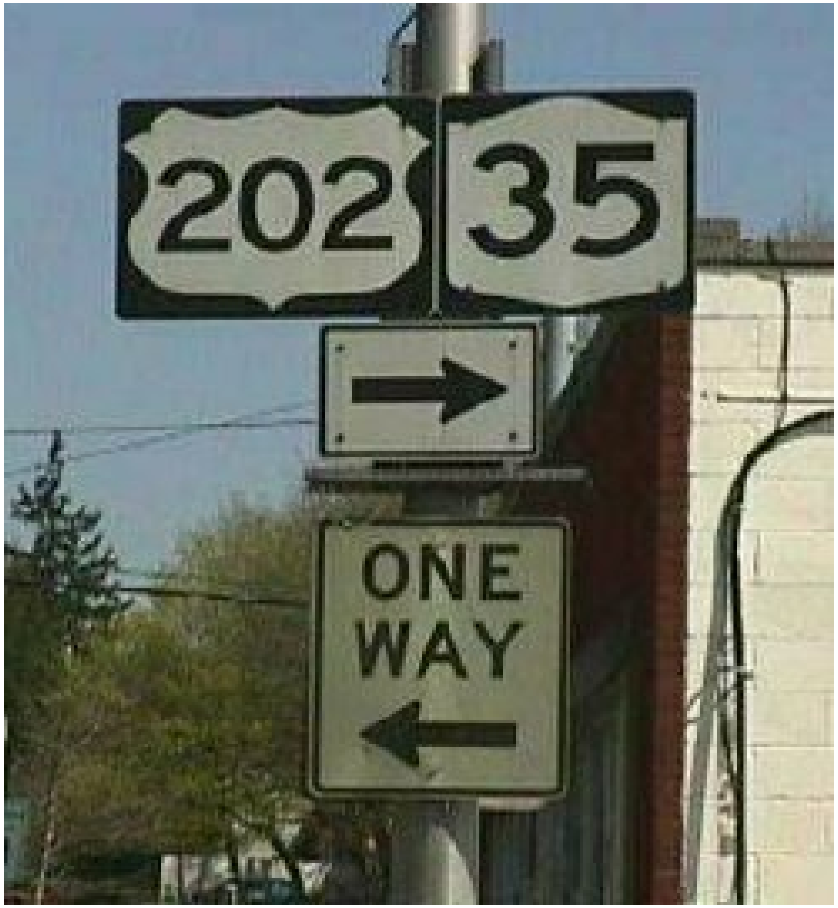
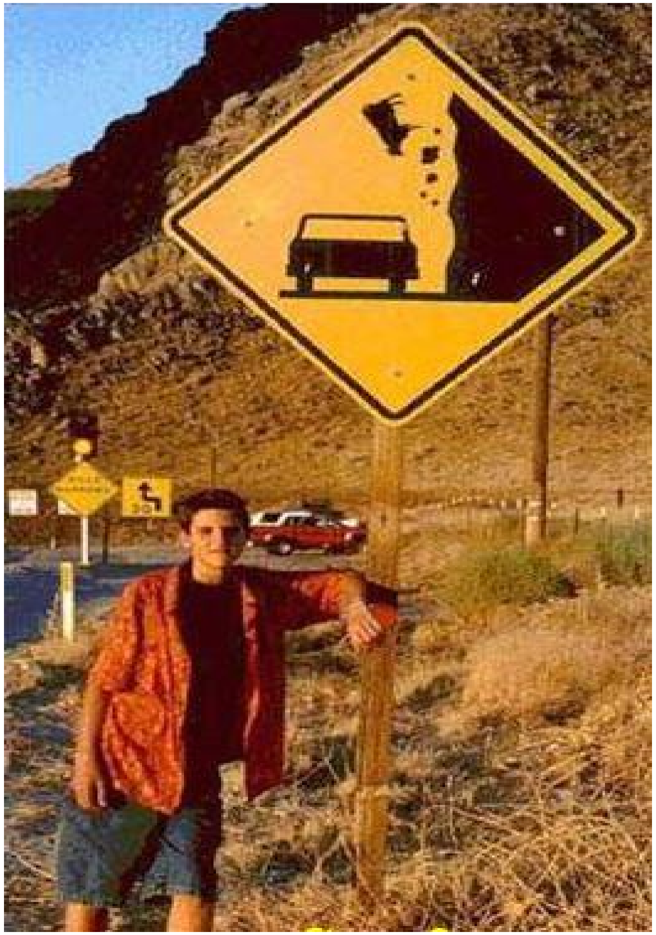


What are the keys to performing HRA?



What are the keys … HRA? (continued)

- Recent research on human error and human actions involved in serious accidents has contributed to building a new perspective on the role of humans in technology and the role of context.
- Examples of research/researchers include:
  - James Reason, *Human Error*, 1990, *Managing the Risks of Organizational Accidents*, 1997, *The Human Contribution: Unsafe Acts, Accidents and Heroic Recoveries*, 2008, *Organizational Accidents Revisited*, 2015.
  - Donald R. Norman, *The Design of Everyday Things*, 1988.
  - E. M. Roth and R.J. Mumaw, *An Empirical Investigation of Operator Performance in Cognitively Demanding Simulated Emergencies*, NUREG/CR-6208, 1994.
  - Steven Casey, *Set Phasers on Stun: And Other True Tales of Design, Technology, and Human Error*, 1998.
  - Others, such as: Eric Hollnagel, David Woods, Micah Endsley

What are the keys …? (continued)

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

What are the keys …? (continued)

Suggestions for some practical exercises on context

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

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

What are the keys …? (continued)

Suggestions for some practical exercises on context

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

Introduction to HRA Outline

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How can we understand human error?

Lesson 1:

How can we understand human error?

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

How can we understand human error?

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

How can we understand human error?

Lesson 2:

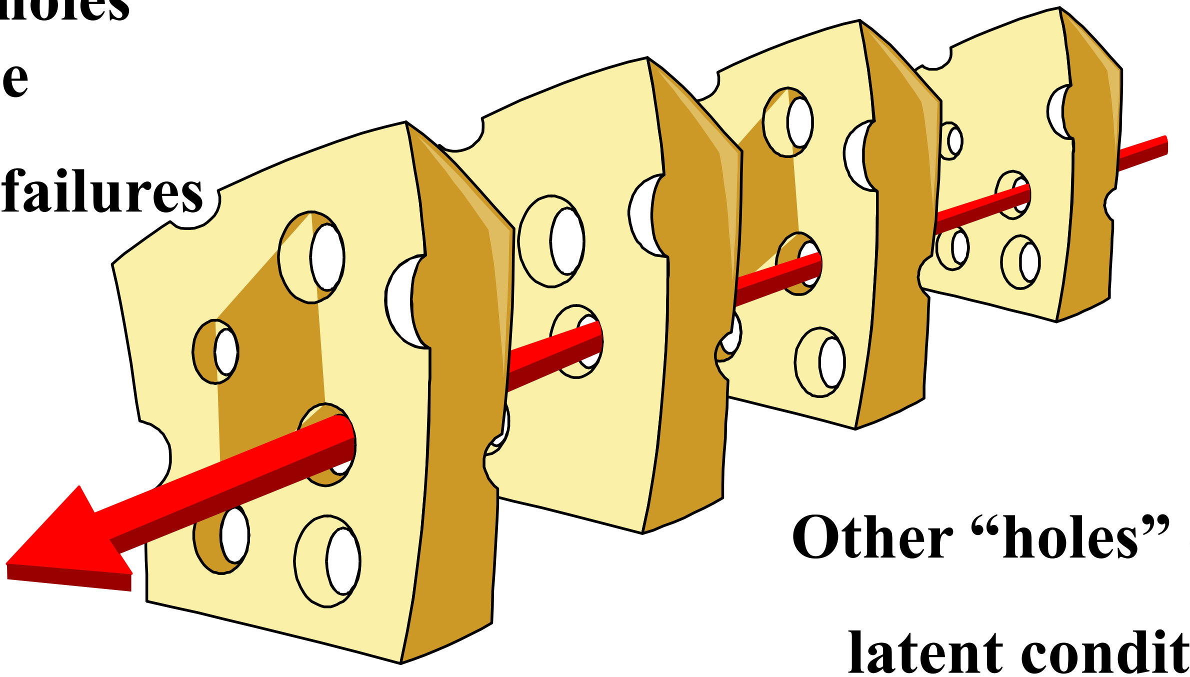
How can we understand human error?

Human error is not the “cause” of a mishap.

How can we understand human error?

- Remember….
  - **The operator is often “set-up” for failure …**
  - **And, the operator is on the “sharp-end” (i.e., simply the last one to touch “the problem”).**
- To illustrate this concept, here is Reason’s Swiss Cheese model of event causation (1990 and 1997)

The 'Swiss Cheese' Model of Event Causation



Some "holes" due

to active failures

Hazards

Harm

Other "holes" due to

latent conditions

Successive layers of defenses, barriers, & safeguards

How can we understand human error?

Lesson 3:

How can we understand human error?

Human error can be predicted.

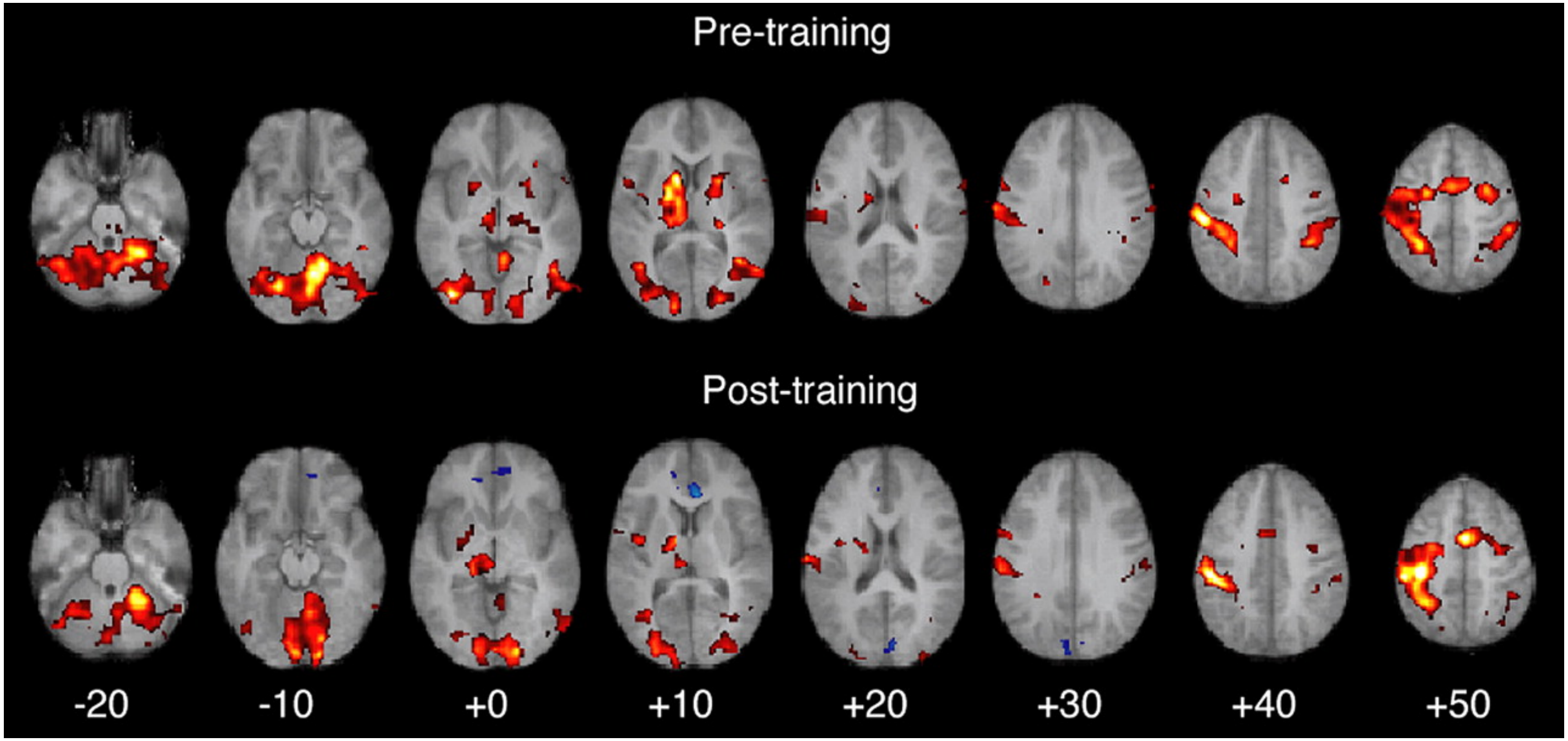
Human error can be predicted because…

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

Human error can be predicted because…

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

Practiced actions become 'automatic'…



…whether we want them to or not.

How can we understand human error?

Lesson 4:

How can we understand human error?

By combining Lessons #1 through #3…

How can we understand human error?

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

How can we understand human error?

- So, it’s important for an HRA analyst to do his best to
  - “Understand the problem” by understanding the context, operator actions and potential failures or errors, etc. (i.e., perform some HRA qualitative analysis)
  - Match “the problem” to the HRA method that best represents the critical aspects of “the problem
- In other words, HRA method selection is important and should be done after you have some “understanding of the problem,” including the likely operator actions and potential operator failures (“errors”).
- In the next presentation topic, we’ll provide resources for guidance on performing HRA, including the most common HRA processes and methods.

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HRA Guidance – How To….

- From our last presentation:
  - Human error literature describes human behavior.
  - Guidance, on the other hand, is a description of **how-to** do something…..
- In this presentation, we will discuss guidance for performing HRA associated with:
  1. HRA processes
  2. HRA quantification methods

HRA Process

- An HRA process is a prescribed set of steps for **how to** perform an HRA that also identifies products of HRA, i.e.,
  1. Identification and definition of human failure events (HFEs),
  2. Qualitative analysis that supports #1 and #2, and
  3. Quantification of each HFE (i.e., assignment of human error probabilities (HEPs)),
  4. Documentation of all of the above.
- Two examples of published stand-alone HRA processes:
  - EPRI's " SHARP1 – A Revised Systematic Human Action Reliability Procedure," EPRI TR-101711, December 1992
  - NRC's "Good Practices for Implementing Human Reliability analysis (HRA)," NUREG-1792, April 2005

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

SHARP1

- Developed in 1980s as a “framework…for incorporating human interactions into PRA…” with emphasis on the iterative nature of the process.
  - Structured in “stages” for systematically integrating HRA into the overall plant logic model of the PRA.
  - Describes and compares selected HRA methods for quantification.
- SHARP1 uses three broad categories of human interactions:
  - Type A: Pre-initiating event interactions
  - Type B: Initiating event interactions
  - Type C: Post-initiating event interactions
    - CP: Actions dictated by operating procedures and modeled as essential parts of the plant logic model
    - CR: Recovery actions
- Emphasizes the importance of dependencies between human interactions (especially with respect to premature screening of important interactions) and defines four classes of dependencies.

NRC's "Good Practices for HRA"

- Written to establish "good practices" for performing HRA and to assess the quality of HRA, when it is reviewed.
- Are generic in nature; not tied to any specific methods or tools.
- Written to support implementation of RG 1.200 for Level 1 and limited Level 2 internal event, at-power PRAs (using direct links between elements of "good practices" and RG 1.200).
- Developed using the experience of NRC staff and its contractors, including lessons learned from developing HRA methods, performing HRAs, and reviewing HRAs.

HRA Processes vs. Methods

- Neither SHARP1 nor NRC’s “Good Practices” specify or dictate which HRA method should be used to perform HRA quantification
- Some resources provide both processes and methods:
  - THERP (NUREG/CR-1278)
  - ATHEANA (NUREG-1624, Rev. 1)
  - Fire HRA Guidelines (NUREG-1921/EPRI TR 1023001)
- ATHEANA and the Fire HRA Guidelines provide:
  - Approaches for identifying HFEs (e.g., EOCs)
  - Techniques for doing certain aspects of qualitative HRA (e.g., determining if an operator action is feasible and, therefore, suitable to be included in PRA)

What are some common HRA methods?

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

Characteristics Addressed by HRA Methods

- Plant behavior and conditions
- Timing of events and the time available for human action
- Locations of the human actions
- Equipment available for use by the operators based on the sequence
- Indications and cues used by the operators and changes in parameters as scenario proceeds
- Environmental conditions
- Relevant training and experience
- Applicability and usefulness of procedural or other guidance

Fire HRA Guidelines (NUREG-1921/EPRI 1023001)

- First report addressing fire-related HRA that goes beyond the screening level presented in NUREG/CR-6850
- Provides a systematic process to identify and define fire HFEs, address fire-specific PSFs, and assess HEPs
- Started with existing Level 1 PRA/HRA practices, but evolved over time as fire HRA practitioners identified key differences in fire HRA and recommended strategies for addressing fire-specific concerns
- Contains 3 quantification methods developed for fire HRA, including a new Scoping approach
- Provides guidance for detailed fire HRA using specific methods
- Forms the basis for this training course

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What are the HRA concerns or issues for fire PRA?

What are the HRA concerns or issues for fire PRA?

- New operator actions to identify and model
  - Fire response operator actions in fire procedures
  - Strategy for the use in response to Fires
- Errors of Commission (EOCs) to identify, screen and define
  - Per the Standard, the possibility that operators respond to spurious indications as if they are "real" must be considered.
  - Screening provides a way to limit the number of EOCs modeled in the fire PRA
- New environmental hazards to model as Performance Shaping Factors (PSFs)
  - Fire effects of smoke, heat, and toxic gases on operators, including transit paths
  - Impact of breathing apparatus and protective gear on operator performance, including communications

What are the HRA concerns or issues for fire PRA? (continued)

- More challenging contexts
  - Potentially wide variations in size, location, and duration of fires and their effects on plant systems and functions
- Different types of operator actions
  - More local actions
  - Multiple tasks such as pulling fuses and then operate valve locally
- Other PSFs or influencing factors
  - Design of ex-control room equipment control locations and alternate shutdown panels
- But, this, and more, will be addressed starting tomorrow.

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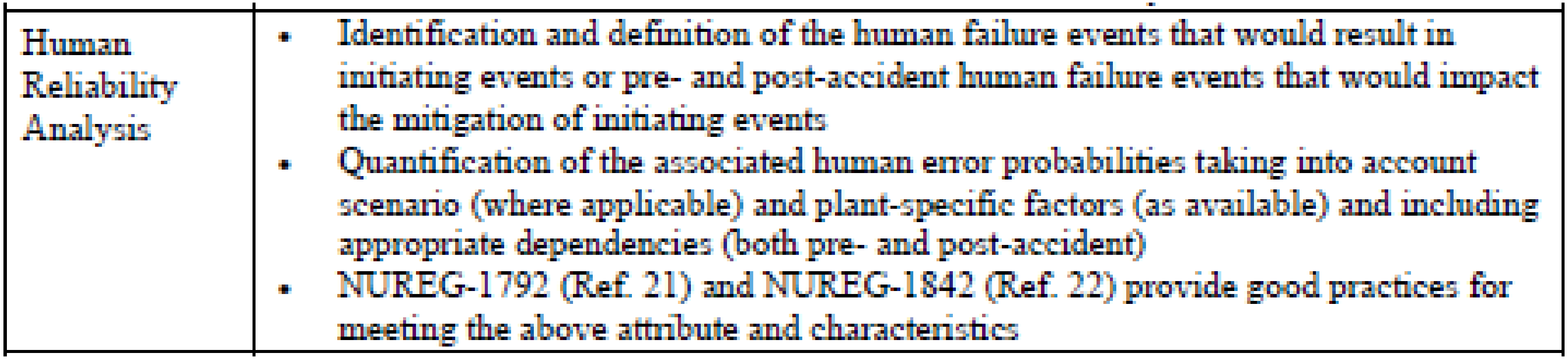
Endorsement and Guidance for PRA

- In 1995, the U.S. Nuclear Regulatory Commission (NRC) issued a Policy Statement on the use of probabilistic risk analysis (PRA), encouraging its use in all regulatory matters.
- Regulatory Guide 1.200 issued in March 2009 is intended to be consistent with the NRC’s PRA Policy Statement.
- It is also intended to reflect and endorse guidance provided by standards-setting and nuclear industry organizations, such as the ASME/ANS PRA Standard (2009).

NRC Regulatory Guide 1.200

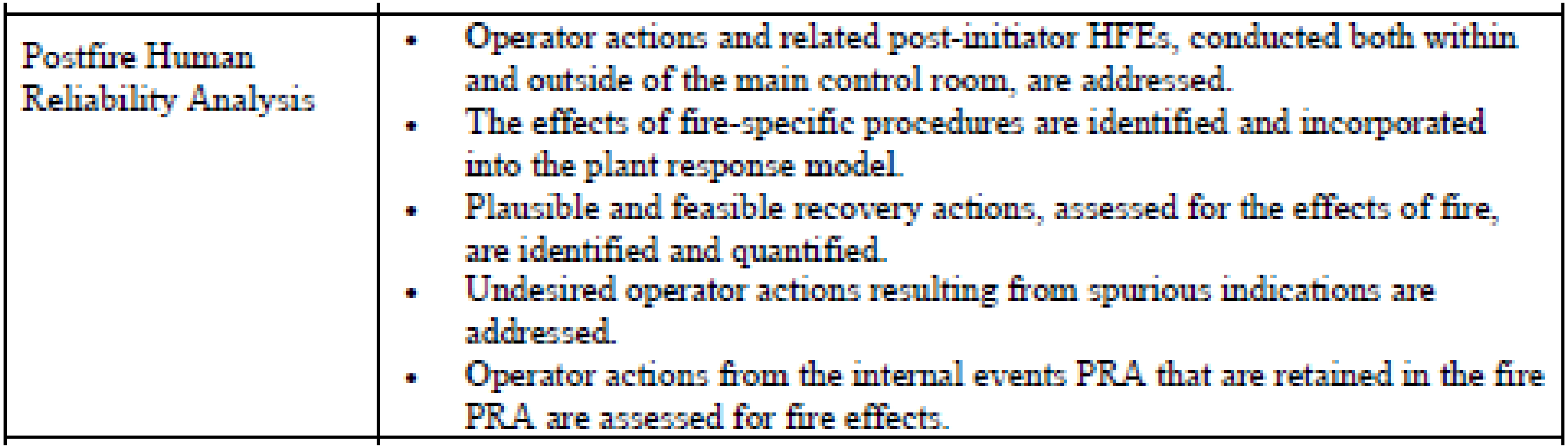
- Title is “An Approach for Determining the Technical Adequacy Of Probabilistic Risk Assessment Results for Risk-informed Activities”
- Provides NRC staff position for one approach to determining technical adequacy of a PRA to support a risk-informed activity
- For each technical element (e.g., HRA)
  - Defines the necessary attributes and characteristics of a technically acceptable HRA
  - Allows use of a standard in conjunction with a peer review to demonstrate conformance with staff position
  - Endorses ASME/ANS standard and NEI peer review guidance (with some exceptions)

RG 1.200 Tech Attributes and Characteristics for Level I HRA



Human Reliability Analysis	• Identification and definition of the human failure events that would result in initiating events or pre- and post-accident human failure events that would impact the mitigation of initiating events • Quantification of the associated human error probabilities taking into account scenario (where applicable) and plant-specific factors (as available) and including appropriate dependencies (both pre- and post-accident) • NUREG-1792 (Ref. 21) and NUREG-1842 (Ref. 22) provide good practices for meeting the above attribute and characteristics

RG 1.200 Tech Attributes and Characteristics for Fire HRA



Postfire Human Reliability Analysis	• Operator actions and related post-initiator HFEs, conducted both within and outside of the main control room, are addressed. • The effects of fire-specific procedures are identified and incorporated into the plant response model. • Plausible and feasible recovery actions, assessed for the effects of fire, are identified and quantified. • Undesired operator actions resulting from spurious indications are addressed. • Operator actions from the internal events PRA that are retained in the fire PRA are assessed for fire effects.

Reg Guide vs. Standard

- RG 1.200 scopes out what is needed in a technically acceptable PRA/HRA, and in some cases amplifies the PRA Standard requirements
- ASME/ANS PRA Standard defines requirements* for a quality PRA
  - Specifies what you need to do.
  - Requirements have been established to ensure PRA quality commensurate with the type of PRA application and/or regulatory decision

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

ASME/ANS RA-Sa–2009

- Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications
- **<u>Part 2</u>** identifies Requirements for Internal Events At-power PRA
- **<u>Part 4</u>** identifies Requirements for Fires At-power PRA
- Many of the technical requirements in Part 2 are fundamental requirements for performing a PRA for any hazard group
- Fire PRA portion adds to and draws from Internal Events section, so <u>have to satisfy elements from both</u>

Objective (Paraphrased) from HRA Technical Element of ASME/ANS PRA Standard

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

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

ASME/ANS PRA Standard

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

ASME/ANS PRA Standard (continued)

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

Capability Category Definitions

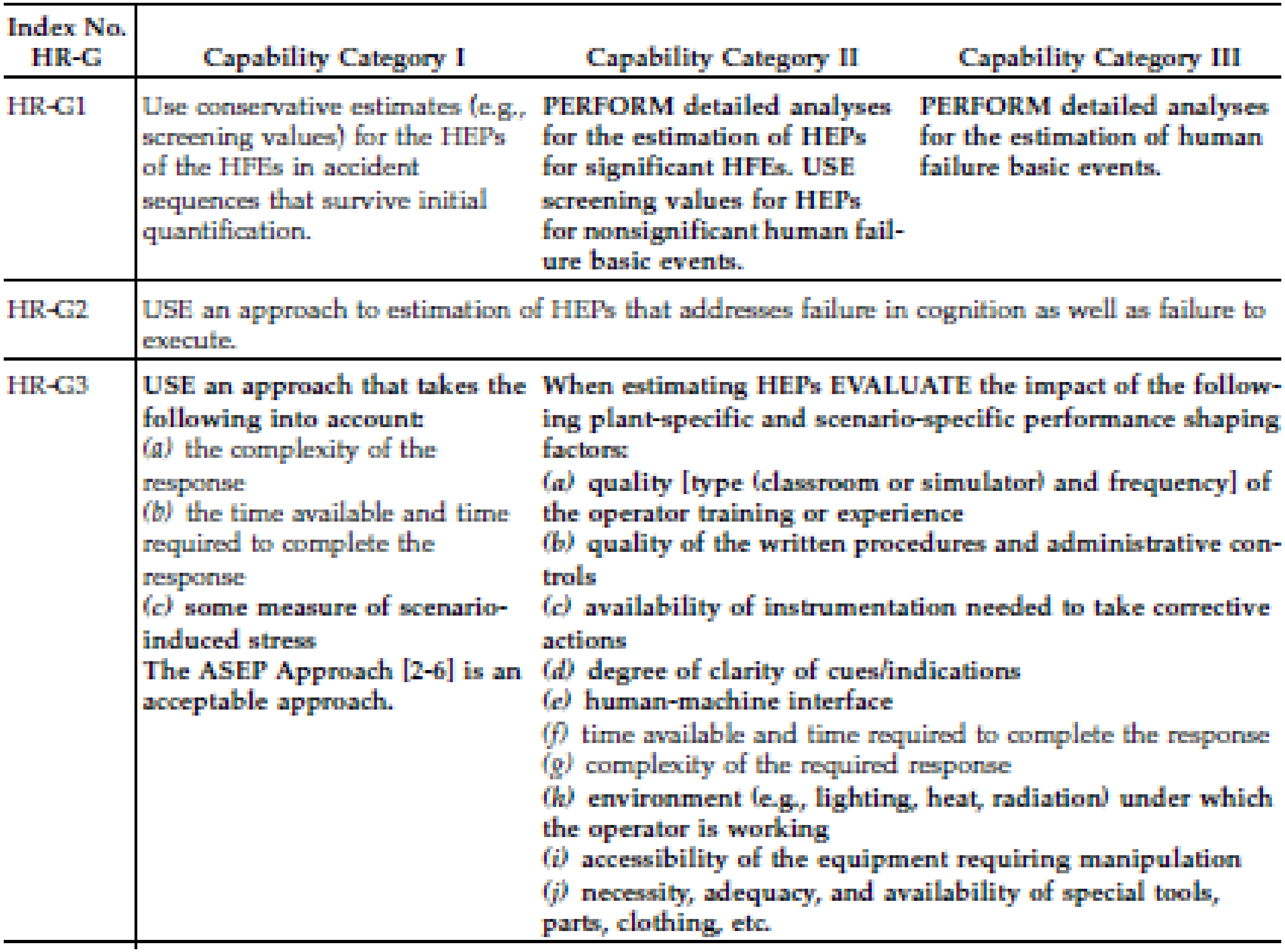
- Capability Category I:
  - Scope and level of detail are sufficient to identify relative importance of contributors down to system or train level.
  - Generic data and models are sufficient except when unique design or operational features need to be addressed.
  - Departures from realism* have moderate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

*the degree to which the expected response of the plant is addressed

Capability Category Definitions (continued)

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

SRs May Differ Across Capability Categories



Index No. HR-G	Capability Category I	Capability Category II	Capability Category III
HR-G1	Use conservative estimates (e.g., screening values) for the HEPs of the HFEs in accident sequences that survive initial quantification.	PERFORM detailed analyses for the estimation of HEPs for significant HFEs. USE screening values for HEPs for nonsignificant human failure basic events.	PERFORM detailed analyses for the estimation of human failure basic events.
HR-G2	USE an approach to estimation of HEPs that addresses failure in cognition as well as failure to execute.		
HR-G3	USE an approach that takes the following into account: *(a)* the complexity of the response *(b)* the time available and time required to complete the response *(c)* some measure of scenario-induced stress The ASEP Approach [2-6] is an acceptable approach.	When estimating HEPs EVALUATE the impact of the following plant-specific and scenario-specific performance shaping factors: *(a)* quality [type (classroom or simulator) and frequency] of the operator training or experience *(b)* quality of the written procedures and administrative controls *(c)* availability of instrumentation needed to take corrective actions *(d)* degree of clarity of cues/indications *(e)* human-machine interface *(f)* time available and time required to complete the response *(g)* complexity of the required response *(h)* environment (e.g., lighting, heat, radiation) under which the operator is working *(i)* accessibility of the equipment requiring manipulation *(j)* necessity, adequacy, and availability of special tools, parts, clothing, etc.	

PRA Standard HLRs for Internal Events HRA (Part 2 Requirements)

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

PRA Standard HLRs for Fire HRA (Part 4 Requirements)

Post Initiator	Refers to Part 2
HRA-A Identify HFEs	HR-E
HRA-B Define HFEs (incorporate in PRA model)	HR-F
HRA-C Assess HEPs	HR-G
HRA-D Recovery HFEs	HR-H
HRA-E Document HFEs/HEPs	HR-I

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

- HLR-HR-G

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

- HLR-HR-H

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

Example of ASME/ANS Standard Post-Initiator HRA Supporting Requirement (SR)

- HR-G1
  - Capability Category I: Use conservative estimates (e.g., screening values) for the HEPs of the HFEs in accident sequences that survive initial quantification.
  - Capability Category II: Perform detailed analyses for the estimation of HEPs for risk-significant HFEs. Use screening values for HEPs for non-risk-significant human failure basic events.
  - Capability Category III: Perform detailed analyses for the estimation of all human failure basic events.

Meeting RG and Standard Requirements

- Peer Reviews are conducted to evaluate the degree to which a PRA has met the RG and Standard requirements
- Findings and Observations (F&Os) are written where deficiencies are found
  - It is expected that these F&Os be addressed before a Licensee Amendment Request (LAR) is submitted for NFPA 805 transition
- Fire PRA/Fire HRA task interfaces are important to address for technical adequacy and standard compliance
  - One could apply a different HRA method, for example, a screening HEP during the quantification of a detailed Fire PRA scenario.
  - In this case, the overall quantification may be acceptable (e.g., PRA Standard Capability Category I), or it may lead to further refinement if best-estimate results (e.g., PRA Standard Capability Category II) are needed.

Guidance from NUREG-1921 and this Course

- NUREG-1921 Fire HRA Guidelines provides assistance (but no guarantee) in meeting the PRA Standard, with emphasis on Capability Category II
- Table 2-1 identifies Fire PRA/Fire HRA task interfaces by PRA Standard element such as accident sequence analysis [AS] or quantification [QU]
- Appendix D correlates PRA Standard sections to Guidelines sections and provides a roadmap for users to perform an assessment of their own fire HRA against the PRA Standard requirements
- The Fire HRA Track presented this week will identify key HLRs and SRs in performing fire HRA/PRA.

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