Demystifying Human Performance Modeling: An Absolute Beginner's Guide to Dynamic Human Reliability Analysis

Ronald L. Boring, PhD

Principal Human Factors Scientist

Human Factors, Controls, and Statistics Department

Idaho National Laboratory

A Boring speaker talking about HRA for an hour and a half

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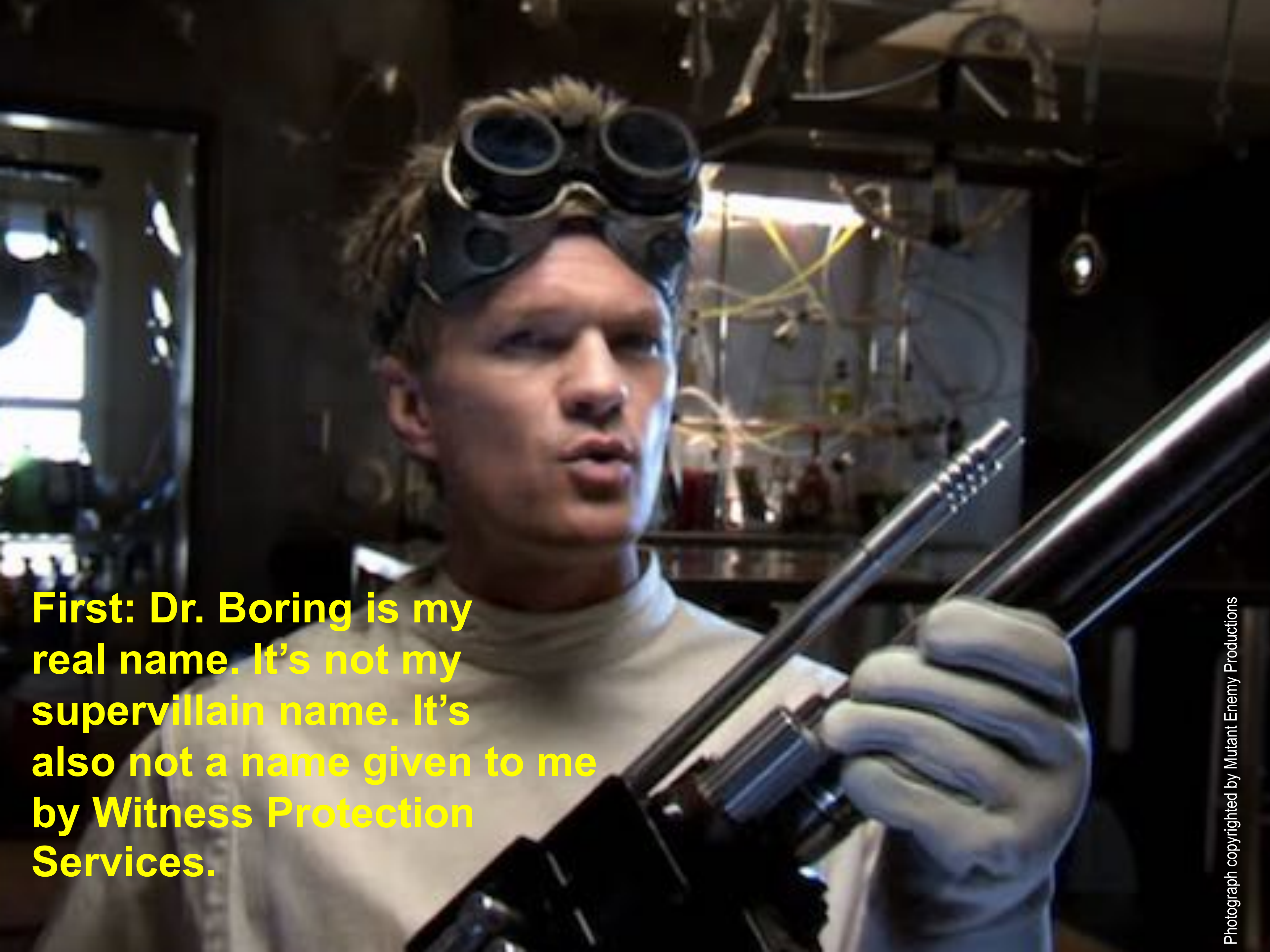
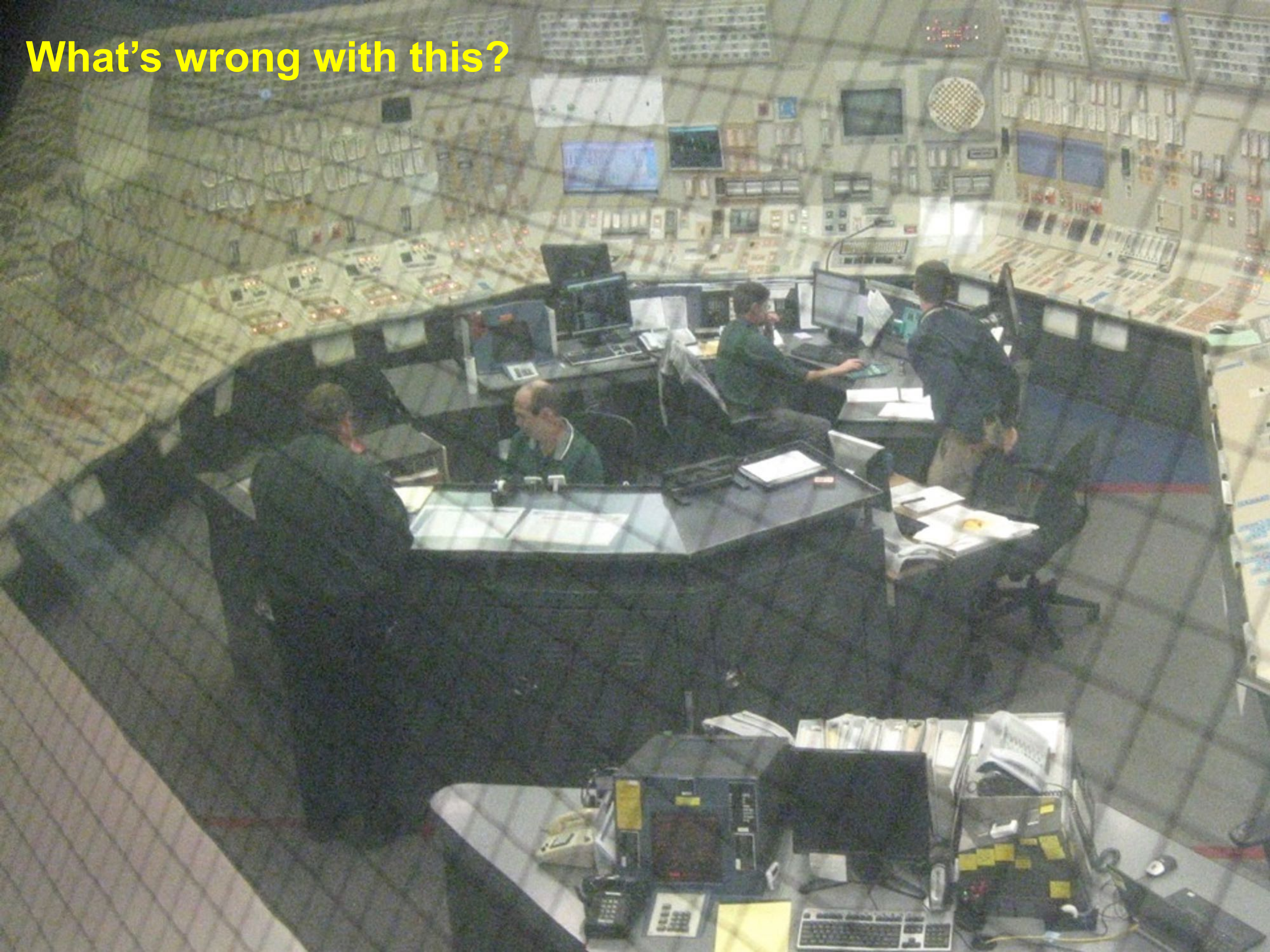


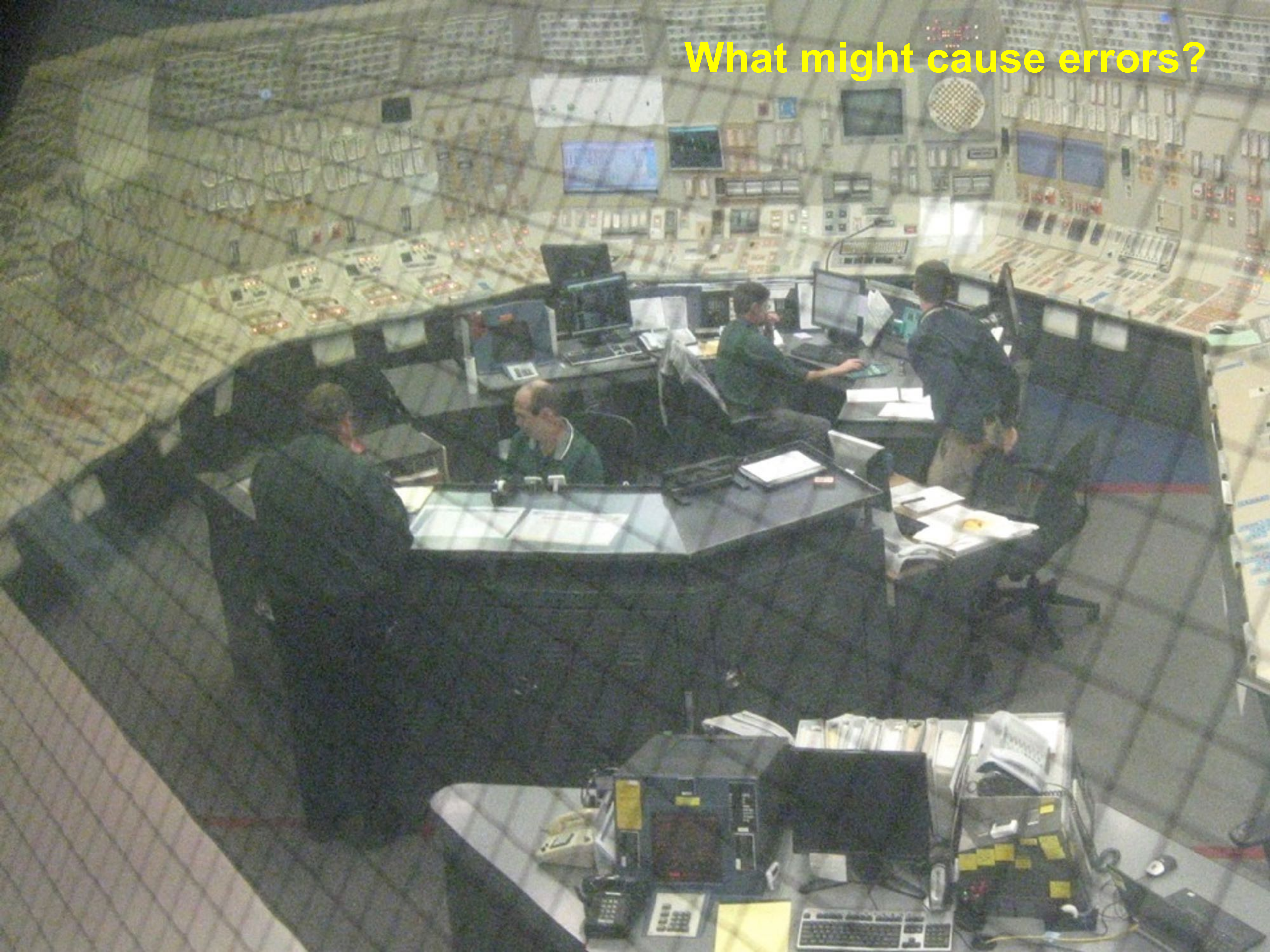
First: Dr. Boring is my real name. It's not my supervillain name. It's also not a name given to me by Witness Protection Services.

One Big Happy Family: Boring = Boeing

What's wrong with this?



What might cause errors?




What's wrong with this?
= human factors and ergonomics
.
.
.
Find it and fix it!
What might cause errors?
= human reliability analysis (HRA)
.
.
.
Find it and model it!

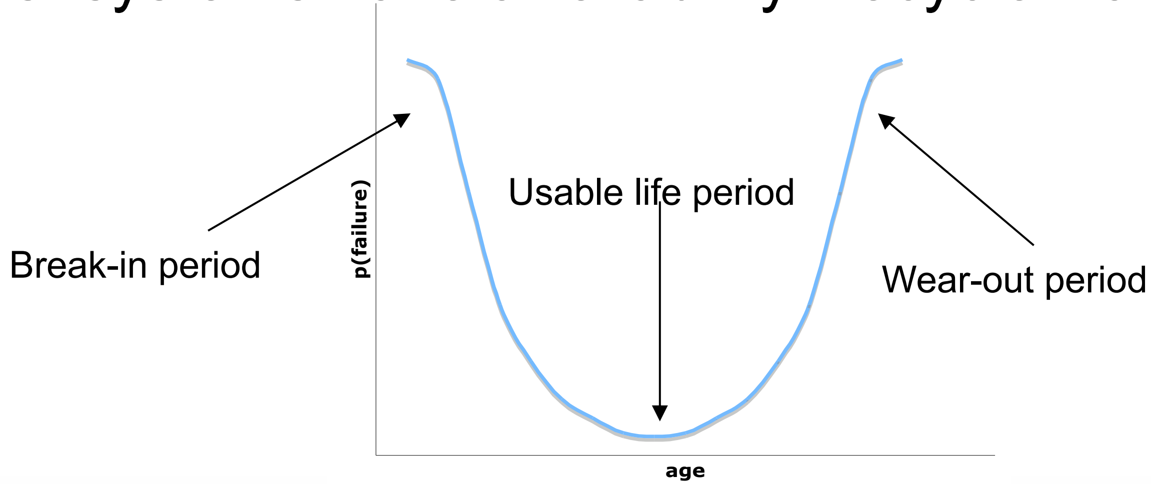
Just the Basics: Good, Old-Fashioned Static HRA

HRA as we know it in 25 slides

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

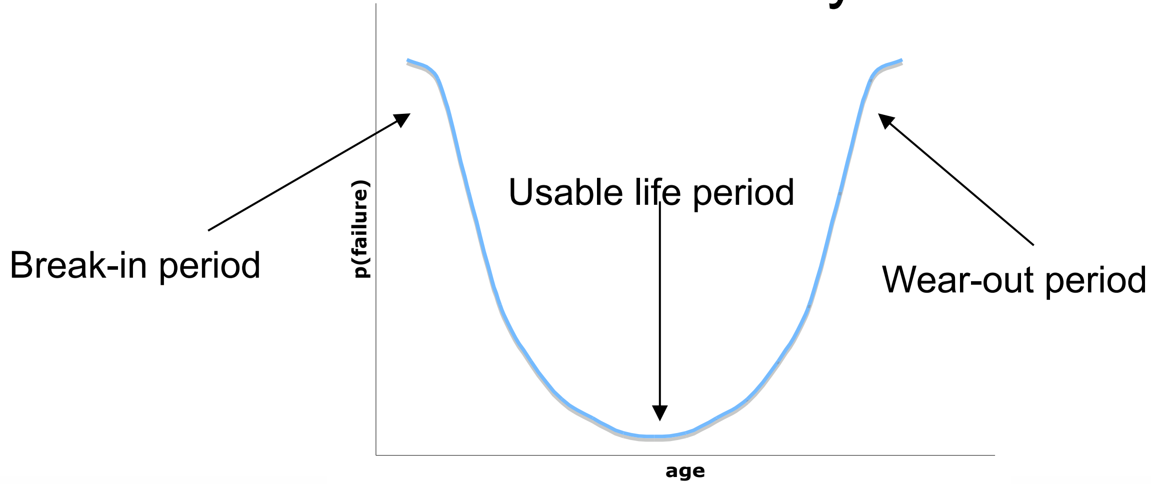


Note: The bathtub curve is used only for illustrative purposes and is not a reflection of actual reliability performance curves

Human Reliability Analysis?

How Does Human Reliability Relate?

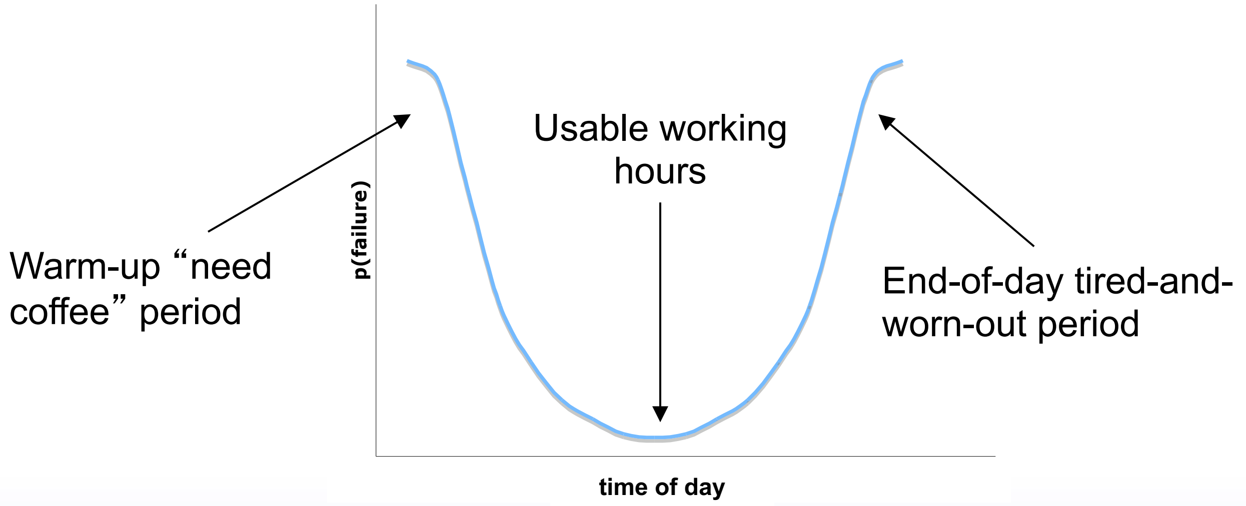
- Do we measure human reliability in terms of a break-in period, usable life period, and wear-out period?
- No! Humans are complex dynamic systems
  - Machines don't have bad days—but humans do



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



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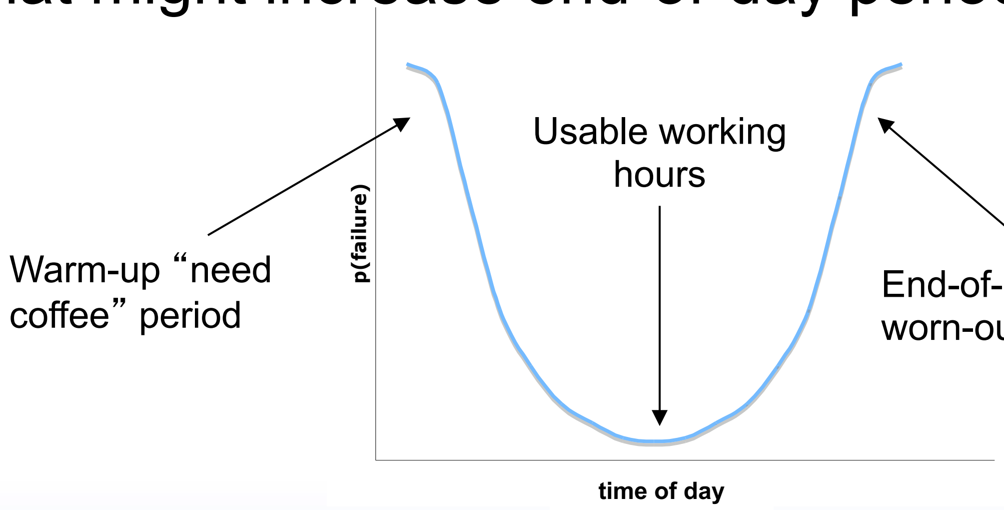
Factors Affecting Human Reliability

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?



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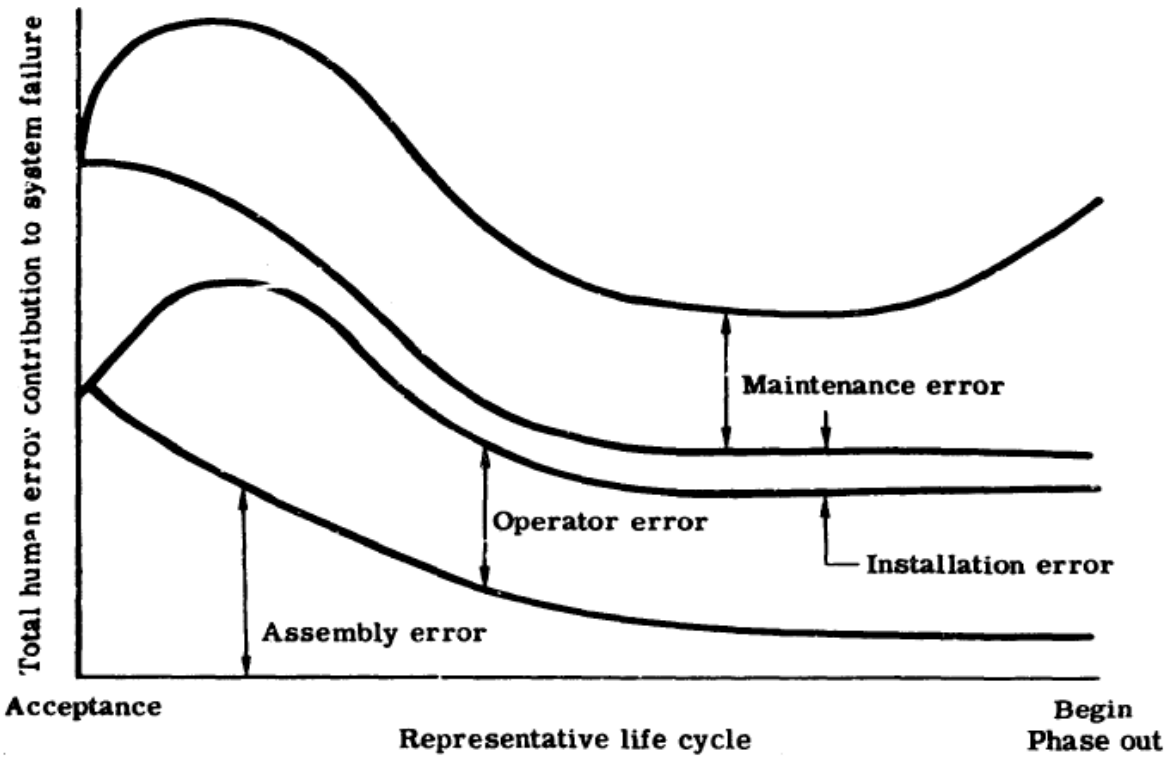
Different Errors Contribute to Failure

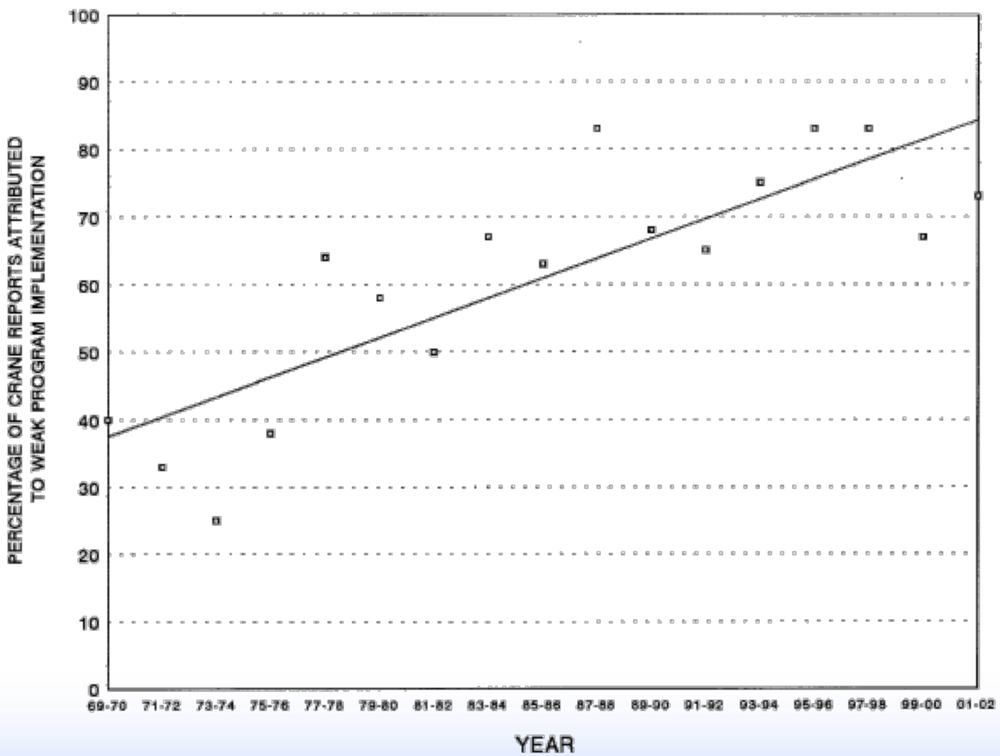


Proportional contribution of the different types of human error to overall failure across a manufactured product life cycle (Rigby, 1967)

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?



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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

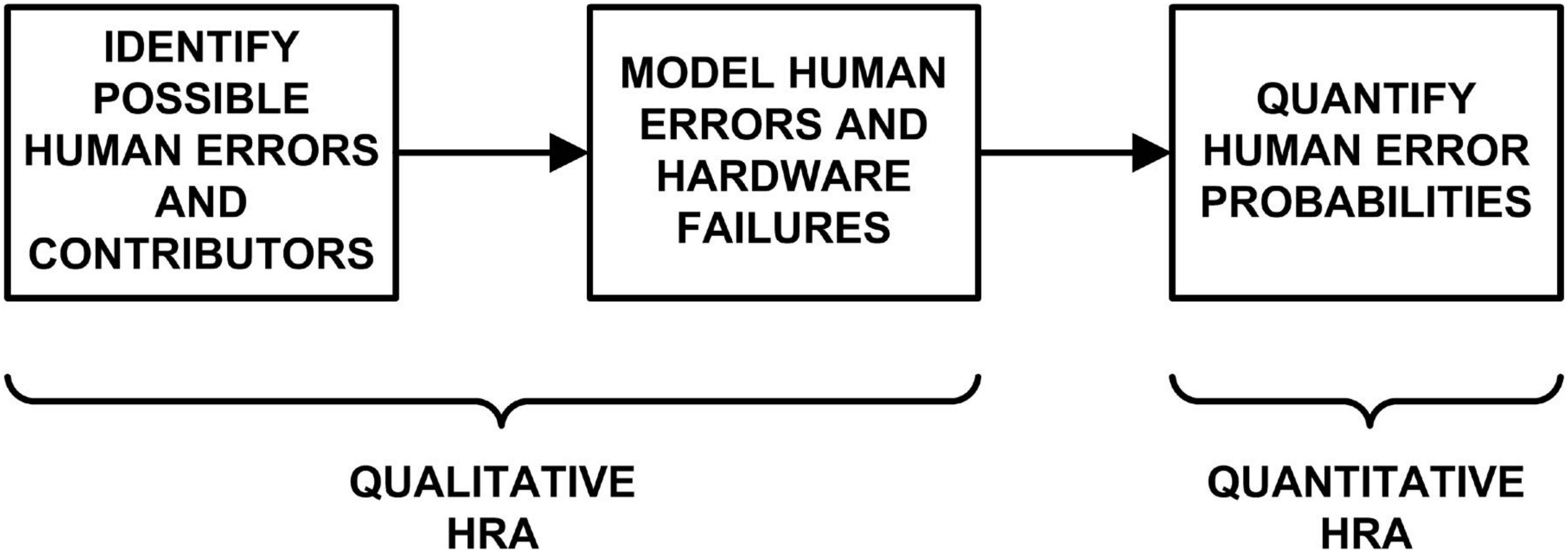
⇩

HRA - Human Reliability Analysis = Human contribution to risk

⇧

HF - Human Factors = Study of human performance when using technology

Three General Phases of HRA



Common Elements of HRA

- **human error (HE):** any human action that exceeds some limit of acceptability, including inaction where required, excluding malevolent behavior
- **human error probability (HEP):** a measure of the likelihood that plant personnel will fail to initiate the correct, required, or specified action or response in a given situation, or by commission performs the wrong action. The HEP is the probability of the HFE
- **human failure event (HFE)**: a basic event that represents a failure or unavailability of a component, system, or function that is caused by human inaction, or an inappropriate action
- **performance shaping factor (PSF):** a factor that influences human error probabilities as considered in a PRA's human reliability analysis and includes such items as level of training, quality/availability of procedural guidance, time available to perform an action, etc.

Source: ASME/ANS RA-Sb-2013

What PSFs might have contributed to this HFE?

Good Practices in HRA (NUREG-1792) PSFs

NUREG-1792 Identifies a list of preferred PSFs

- Not exhaustive list, but minimum to be considered

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"

What’s the error rate of this HFE?

Two Levels of Quantitative Realism

1. **Screening Analysis**
   - Conservative 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 might be risk significant
     - Conservative values are higher than analysts would normally use
   - Determine if the HFE affects the event outcome
2. **Detailed Analysis**
   - HFEs that are found to be potentially significant contributors are analyzed in greater detail using more realistic quantification using an available HRA method

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Quantitative HRA Methods

Expert Estimation

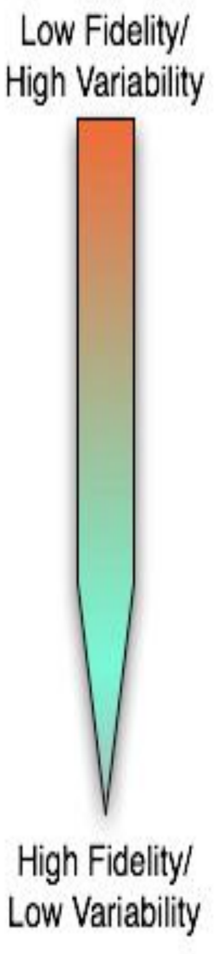
- Determination of an HEP based on expert knowledge of the likelihood that a person would falter in a given context

Performance Shaping Factors (PSFs)

- Use of factors known to degrade or improve human performance over an established baseline
- PSFs often treated as multipliers on a nominal HEP

Frequency Based Estimation

- Use of performance data derived from observation of similar events or contexts
- Error is the number of observed failures divided by the number of observed trials in which the human performed the task



HEP Ranges

- **Average or nominal performance** in the range of 1E-2 to 1E-3 (error 1/100 to 1/1000 times)
- **Exceptionally good performanc**e may be seen in the range of 1E-4 to 1E-5 (error 1/10,000 to 1/100,000 times)
  - Better than some hardware!
  - Temptation to want to drive HEP lower, but this is not realistic
  - Some convergence in HRA to set lower bound at 1E-5
    - At this rate, you are actually still more likely to die at any given time than commit an error!
- **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 greater unreliability than is typical for hardware

Stages to Calculate HEP

Nominal Error Rate (Nominal HEP)

- Generic error rate for a type of activity
- Typically provided by the method

Base Error Rate (Base or Basic HEP)

- Nominal HEP modified for influences on performance such as PSFs
- These may increase or decrease the nominal HEP

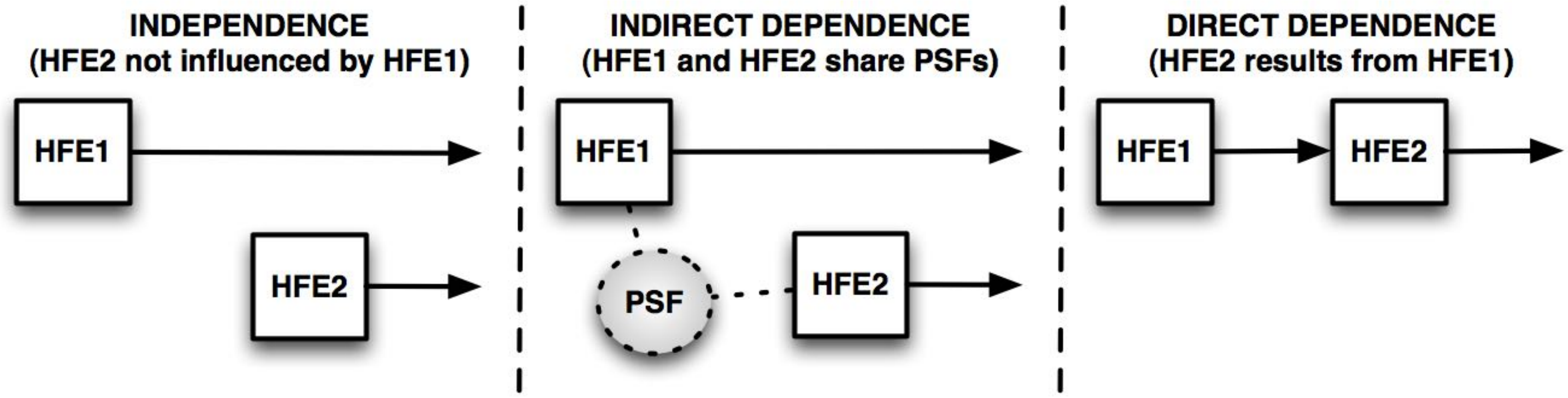
Conditional Error Rate (Conditional HEP)

- Base HEP modified for any dependence or recovery factors in a sequence of events

Dependence

Dependence (Dependency) = Relationship between HFEs

- Error begets error
- Success begets success



What's the error rate of this HFE?

SPAR-H as a simple quantification method

- Simplified Plant Analysis Risk-Human Reliability Analysis Method (NUREG/CR-6883)

Nominal HEP

- Is the task cognitive or behavioral?
- Cognitive: Nominal HEP = 1E-2 (1/100)
- Behavioral/Action: Nominal HEP = 1E-3 (1/1000)

Basic HEP

- Multiply Nominal HEP x PSF multipliers

SPAR-H Quantification

- SPAR-H Worksheets are used to quantify HEPs by considering 8 PSFs that may increase/decrease likelihood of error

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

<u>Ergonomics/HMI</u>

- ***Missing/Misleading*** **→ x 50**
- ***Poor*** **→ x 10**
- ***Nominal*** **→ x 1**
- ***Good*** **→ x 0.5**

When to Apply HRA

Retrospective HRA

- Focused HRA to help identify risk significance of past incidents
- Estimate HEPs for salient HFEs given the context
- Identify ways to lessen likelihood of recurrence of incident
- Example: U.S. NRC's Significance Determination Process (SDP)

Prospective HRA

- Identify, model, and quantify HFEs in PRA more broadly to estimate risk
- Example: Licensee HRAs for New Builds

History of HRA

Alan Swain, Developer of THERP, 1972

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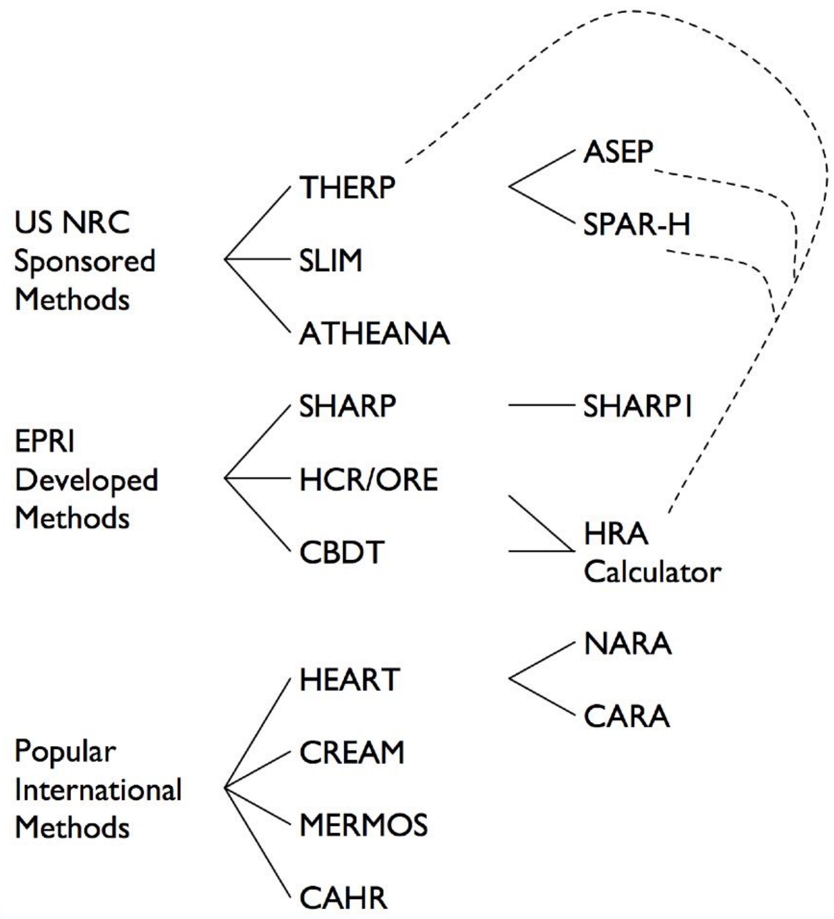
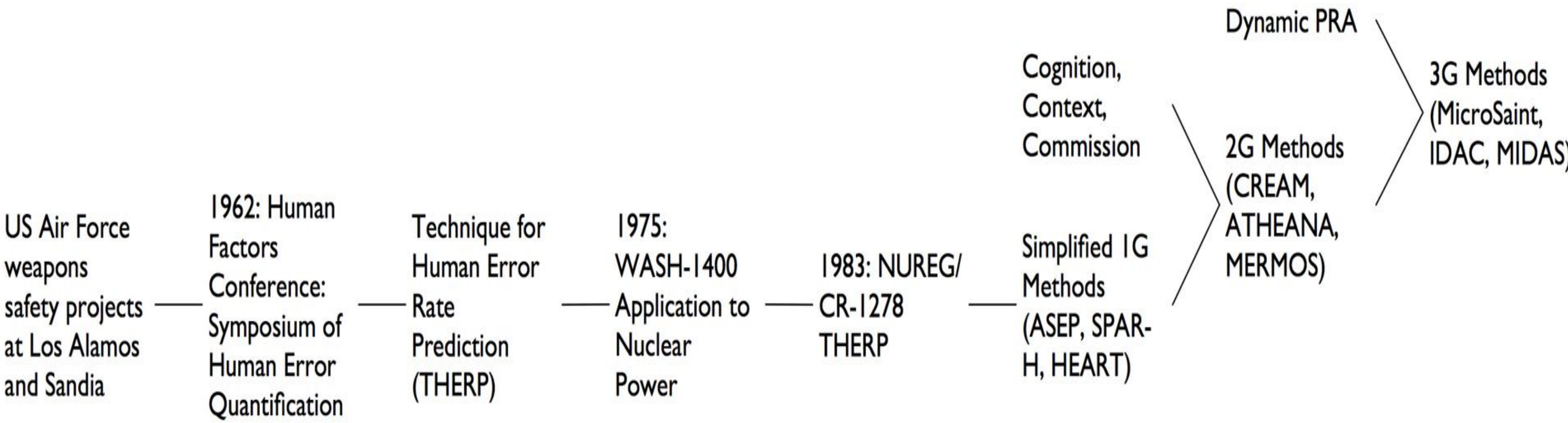
Evolution of Selected HRA Methods



History of HRA (Sample of Methods)



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**


Are we having fun yet?

So, what's wrong with static HRA?

plant operations are said to be

99% boredom and 1% sheer terror

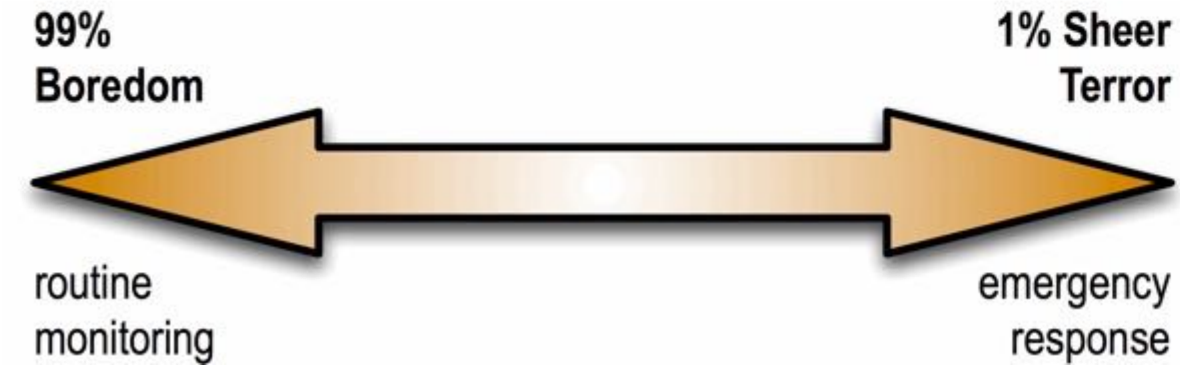
(also used to describe war, flying, and parenting)

for nuclear power plant operations, more appropriate to say "99.99999% routine operations and 0.00001% response to abnormal events"

two extreme environments

Most of the Time: Slow System that Must be Monitored and Sometimes Changed

Rarely: Something Goes Wrong that Requires Response to Prevent Radioactive Release or Reactor Damage



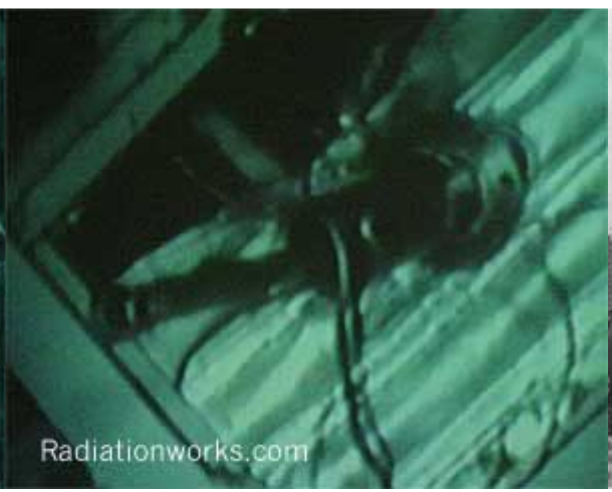
rarely…


Idaho Falls, Idaho, USA
A quiet, out-of-the-way place to build 52 proof-of-concept reactors

SL-1 Reactor

January 3, 1961, Idaho Falls:

- Maintenance personnel were supposed to lift radioactive control rods about four inches from neutralizing sheath; instead, lifted about 12 inches, causing vaporization of reactor core
- Control rods shot from reactor head, killing 3 plant personnel



human factors behind the SL-1 meltdown

- Poor design for adjusting control rods
- Poor training of personnel
- Poor feedback on position of control rods
- Rod operator was having a bad day
  - Wife having affair with other operator
  - Wife had just asked for divorce

Fukushima Dai-Ichi

March 11, 2011, Fukushima, Japan:

- Offshore earthquake followed by 12m tsunami wave damaged plant and disrupted offsight and backup power needed to cool reactor
- Crews lost all instrumentation and controls in control room
- Failed to restore power, resulting in hydrogen explosions and three reactor meltdowns and spent fuel leaks

human factors behind Fukushima

- The plant was not designed to withstand a tsunami of that magnitude
  - Plant safety backup systems such as emergency generators were equally vulnerable
- Crew and first responders not well trained on this magnitude of emergency response
- Inadequate severe accident management guidelines
- Authorities slow to react to event
  - Failure to prioritize emergency response to plant in face of large scale damages in Japan

First and most recent major nuclear accidents…what do they have in common?

Both had events that were considered improbable and had not been modeled in risk analyses

Both had events that continued and had to be addressed even after meltdown

Three Levels of Analysis in HRA

- **Level 1 HRA** concentrates on the sequences of human actions that may contribute to loss of core structural integrity
- **Level 2 HRA** concerns human actions that may contribute to radioactive release after the loss of core structural integrity
- **Level 3 HRA** starts from the Level 2 results, and considers human actions that may contribute to effects on the environment and public health following the loss of core structural integrity

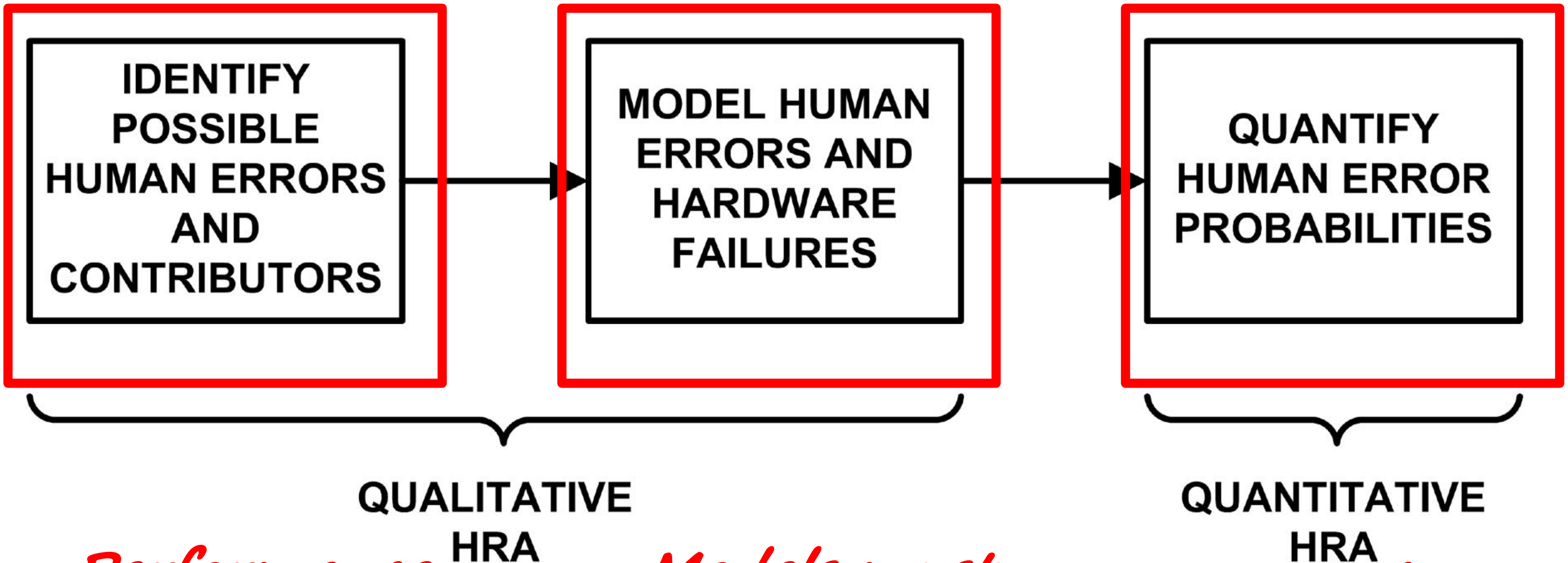
The Problem

- Most HRA has been developed for Level 1:
  - At power
  - Internal events
  - Post-initiator
  - Control room actions
  - Emergency operating procedures (EOPs)
- Very little HRA developed for Level 2:
  - Need to develop HRA beyond Level 1 applications
  - Need to adapt simplified HRA methods for these complex domains

Differences Between Level 1 and 2 HRA

	Level 1	Level 2
Procedures	EOPs	SAMGs
Location	Main Control Room	Technical Support Center
Indicators	Available	Degraded
Decision-Making	Clear Success Paths	Prioritize Safety Tradeoffs
Field Actions	Normal	Difficult
Staffing	Optimal Complement	Additional Personnel
Equipment/PPE	Normal	FLEX/EME
HRA Modeling	Understood	Not Well Developed

The Challenge with Level 2 HRA



Performance drivers not well reflected in existing methods

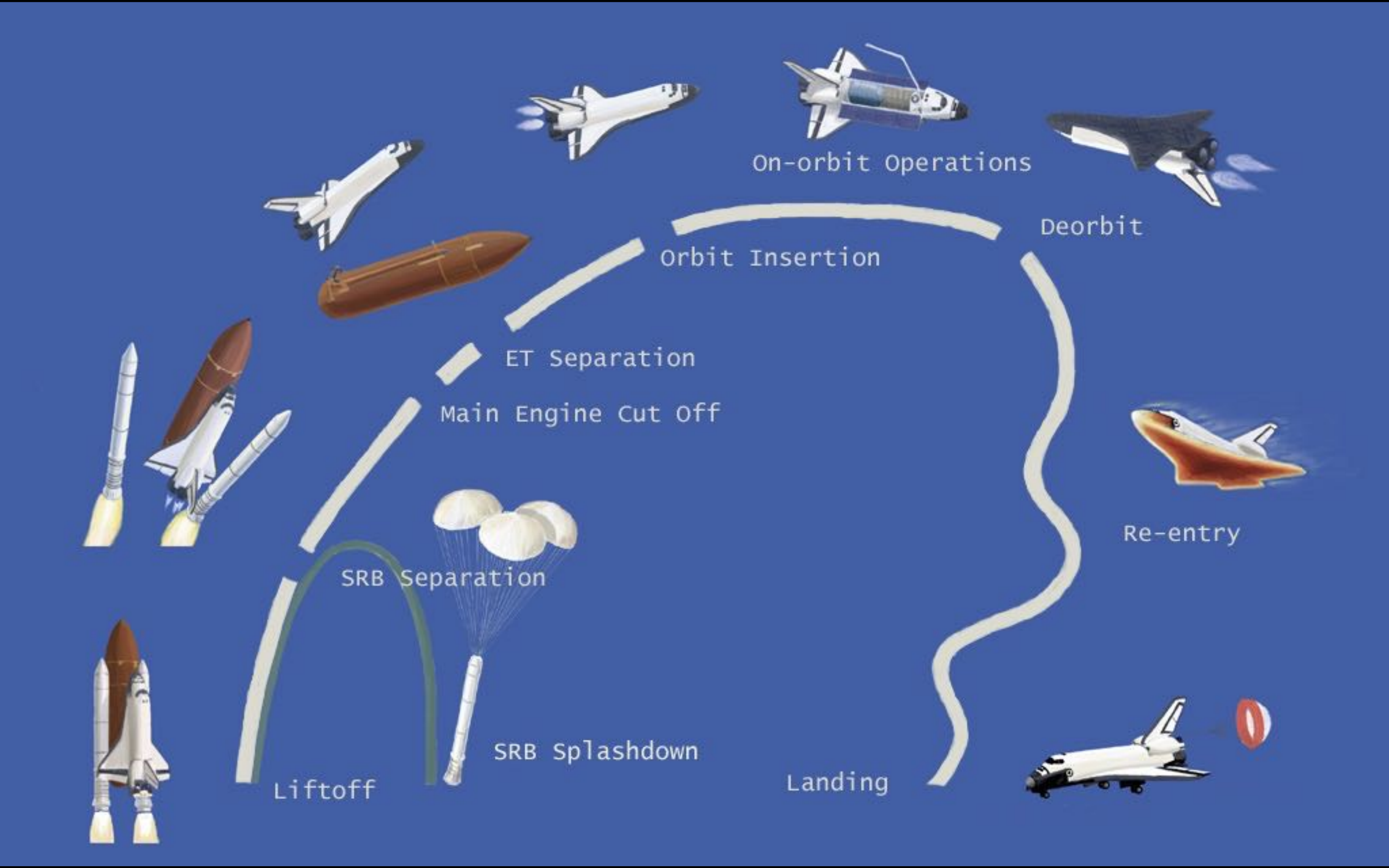
Models must encompass unexampled outcomes

Operating performance not well accounted for in existing methods

Rethinking HRA: Dynamic HRA in a Nutshell

What do we mean by *dynamic*?

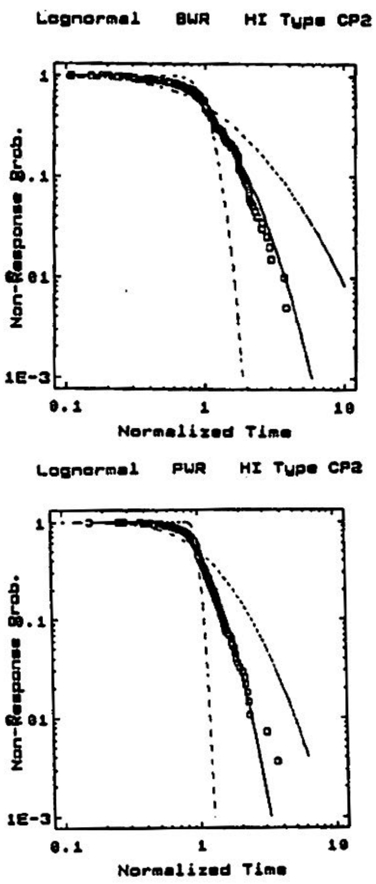
Is it dynamic phases?

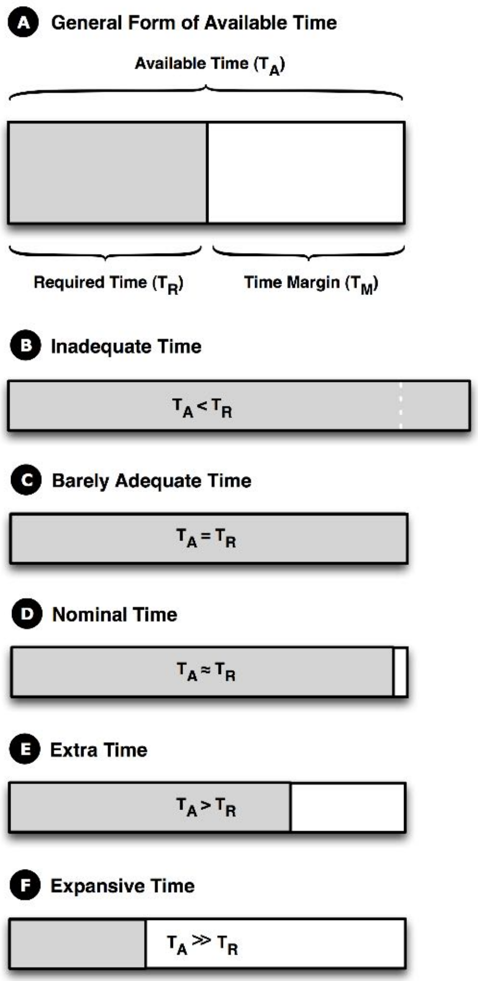


Phases can be modeled in static HRA

Does it have something to do with time?

CP2: When this parameter occurs, then responds





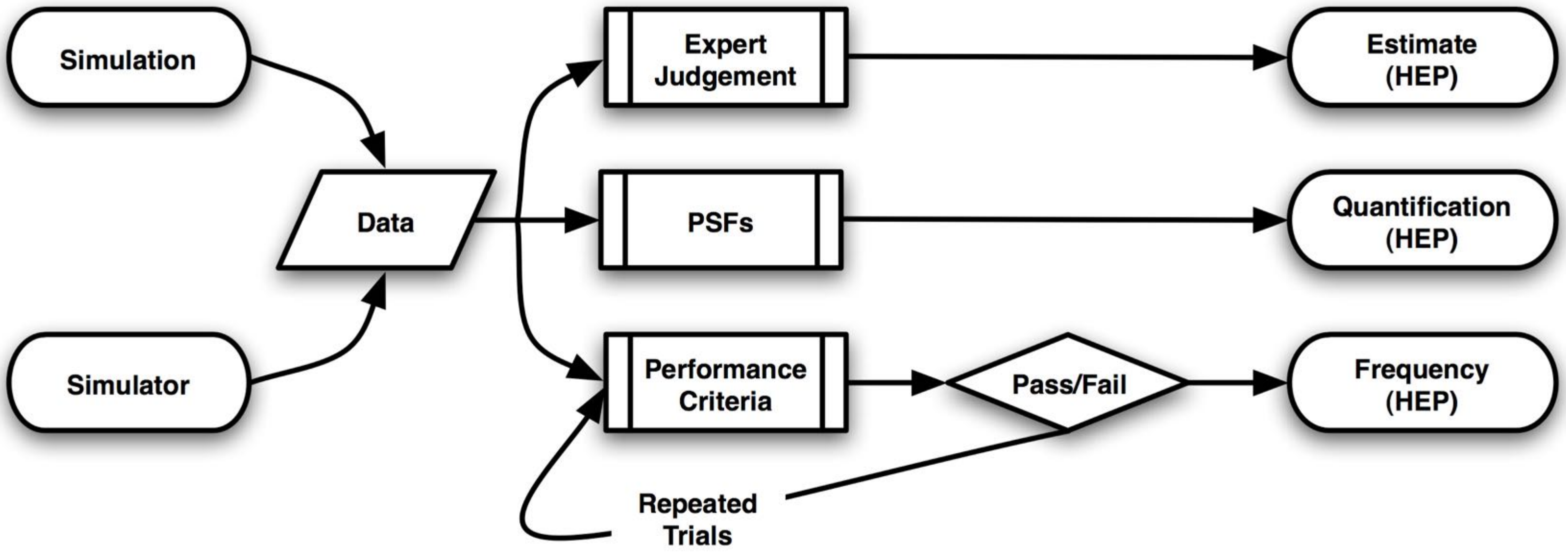
Time is already considered in static HRA

Is it post accident?

Accidents are modeled in static HRA

Definition of Dynamic HRA

- HRA that uses simulation of systems and humans to predict evolution and different possible event outcomes
- Simulation: virtual environment + virtual human



Model:
normative, fixed representation of system that considers likelihood of different finite set of predefined outcomes

Simulation:
stochastic, functional representation of systems that can be changed to represent infinite outcomes at different points in time

Why do we need dynamic HRA?

Reasons for Dynamic HRA

Modeling fidelity

- Potentially higher fidelity reflection of human activities

Individual differences

- Modeling actual range of operators better accounts for performance variability than does *uncertainty* calculation

Post-accident evolution

- Accidents are not the end state; they are beginning of process, often outside pre-scripted procedures

Unexampled events

- *Stuff* happens, often beyond what we ever imagined, and it would be nice to be able to look ahead when it happens

An Interesting Observation

David Meister on History of HRA

- Early human factors sought to describe human interaction with technology in order to improve technological interface
- In contrast, early human reliability research sought to catalog human performance in order to create predictive models
  - Early work on human reliability centered on collection of data and modeling
  - This emphasis on modeling is now more focus of contemporary human performance modeling (and artificial intelligence) than HRA

Dynamic HRA Approach: Human Modeling

Take static HRA approach and make dynamic

- Move beyond worksheet approaches and create dynamic model of operator
- Adapt static HRA method (e.g., SPAR-H) to dynamic model that can interface with INL codes

Test assumptions of static method when made dynamic

- Static HRA is analyzed at the Human Failure Event (HFE) level
  - e.g., failure to initiate safety injection
- Dynamic HRA requires sub-task modeling
  - e.g., individual procedure steps behind safety injection
  - Translating event-level methods to sub-task level

Tie into thermo-hydraulics plant models at Idaho National Lab

- MOOSE: mutiphysics problem solver engine
- RAVEN: RELAP thermo-hydraulics mixed with PRA

the challenge of multiphysics

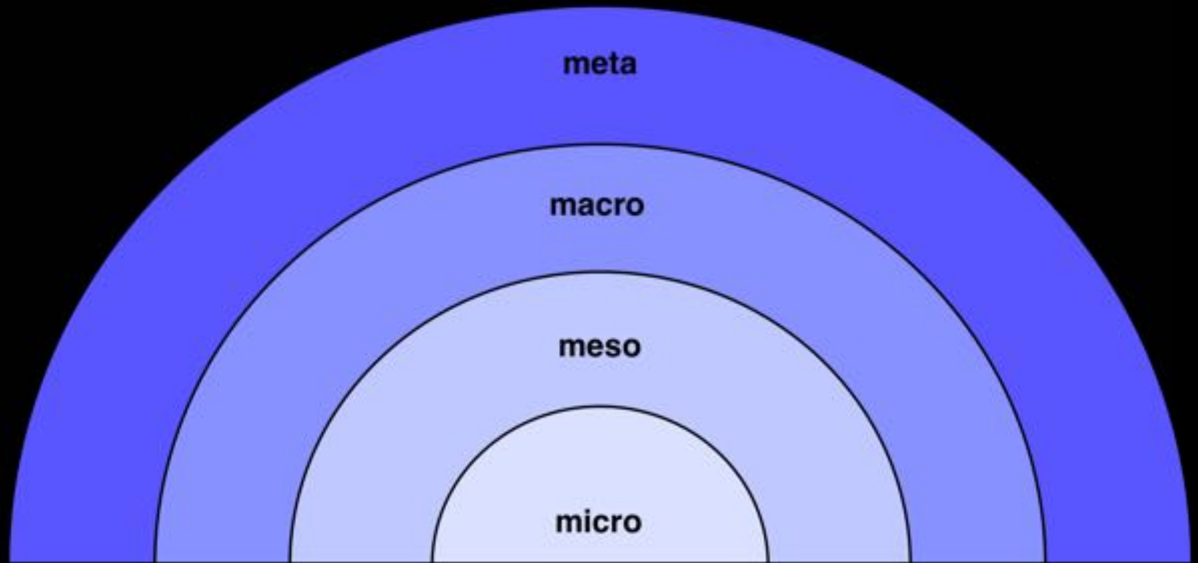
Multiphysics looks mainly at two levels

- component (micro) and system (macro)
- I’m not quite sure what “metaphysics” means here ☺

From a human perspective

- micro (operator) – meso (crew) – macro (plant) – meta (community/organization)

A complete multiphysics plant model needs all levels



Meme for Dynamic HRA

What human factors researchers think I do.

What multi-physics researchers think I do.

What management thinks I do.

What PRA thinks I do.

What I actually do.

Practical Considerations

A Big Undertaking

- Billions have been spent on AI, and the results are still inconclusive
  - For routine types of activities, we can do a pretty good job modeling human decisions and actions
  - For complex decision making, the irrational nature of thought opens up huge uncertainties
- Adapting one of the full-fledged AI models to HRA is beyond budget and scope of our porject
  - Building on initial success of ADS-IDAC is most fruitful way to move forward with simulation based HRA

Our Framework

Since We'll Be Tying into Idaho's Animals…

- HUNTER: Human Unimodel for Nuclear Technology to Enhance Reliability
  - A *unimodel* is a cognitive framework that favors simplified decision models
  - This will produce the MOOSE-HUNTER or RAVEN-HUNTER system
  - (We're looking for a friendlier mascot, as we do not want to kill any of these code animals)

Seven Deadly Sins Stopping Us from Dynamic HRA

1

Don’t wait for data.

We’ve been complaining about a lack of data since THERP.

We can start to build dynamic models based on what we know now to test what we still need to know.

Dynamic HRA can set the research bounds.

2

Don’t wait for a full system simulation.

We are able to work with early stage thermo-hydraulic code as well as complete plant models.

Most times, a simple system model is sufficient to yield a dynamic simulation that can be used with dynamic HRA.

3

We don’t need full artificial intelligence for dynamic HRA.

Many safety-critical processes have a finite range of actions and decisions. We can start bu modeling simplified virtual operators. Virtual operators should be informed by AI without being AI systems.

4

Our human reliability methods are still largely paper driven.

It’s time to lose the paper! As these HRA methods are digitized, we have the opportunity to plug them into simulations.

It is not a big leap from digital to simulated!

5

Dependence is a complex and unsolved problem in HRA.

How do we aggregate HEPs to bridge static and dynamic results? Dependence models break down and don't allow us to quantify large sequences of subevents.

6

Start small!

Many early dynamic HRA methods stumbled on the complexity of modeling human performance.

Start with simple examples and models to prove what works, step-by-step.

HRA is as complex as all of psychology; we will never model all of it!

7

Don’t drive backwards.

We are driving our plants looking behind what has happened instead of looking ahead to what might happen. Dynamic HRA may be the key to prognostic and predictive systems that can aid the actual operators.

questions ?

RONALD.BORING@INL.GOV