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Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut
Vinh N. Dang

Human Reliability Analysis

Menschliche Zuverlässigkeit

Vorlesung 'Reliability of Technical Systems', W. Kröger

Human Reliability Analysis (HRA)

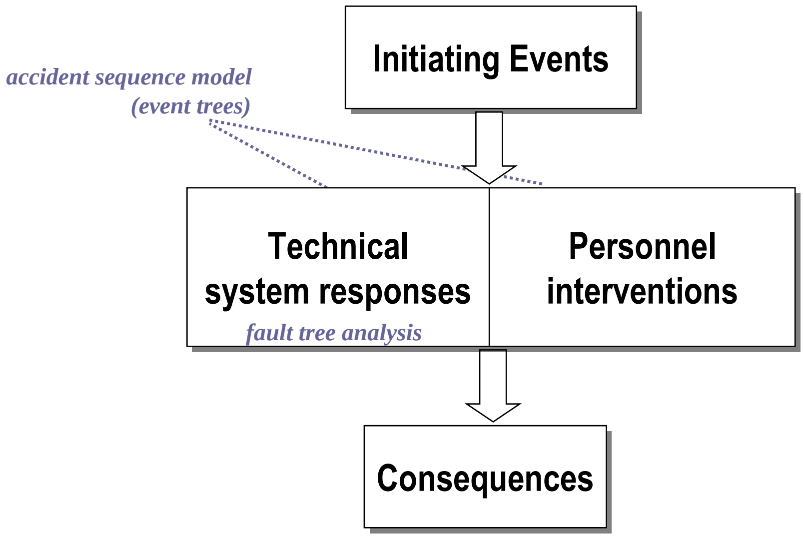
1. Analysis of human performance in Probabilistic Safety Assessments
2. Performance factors and qualitative analysis
3. Methods for quantification
4. Identification and selection of Human Failure Events
5. Dependencies
6. Human Performance Limiting Values

Human performance affects safety …

- **Positively - Humans are**
  - –Good at detecting patterns
  - –Able to handle uncertain situations
  - –Capable to solve unforeseen problems
- **Negatively**
  - –Slips and mistakes
  - –Biases

so: modeling human performance is essential to
- –addressing realistic accident scenarios
- –understanding the relative importance of the hardware and human contributors to risk

The PSA Model



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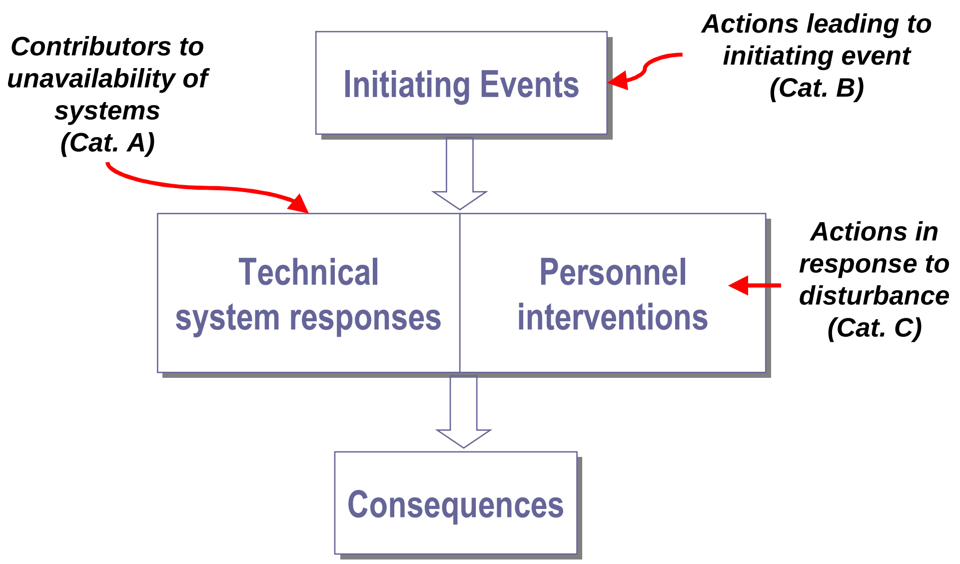
HRA in the PSA model



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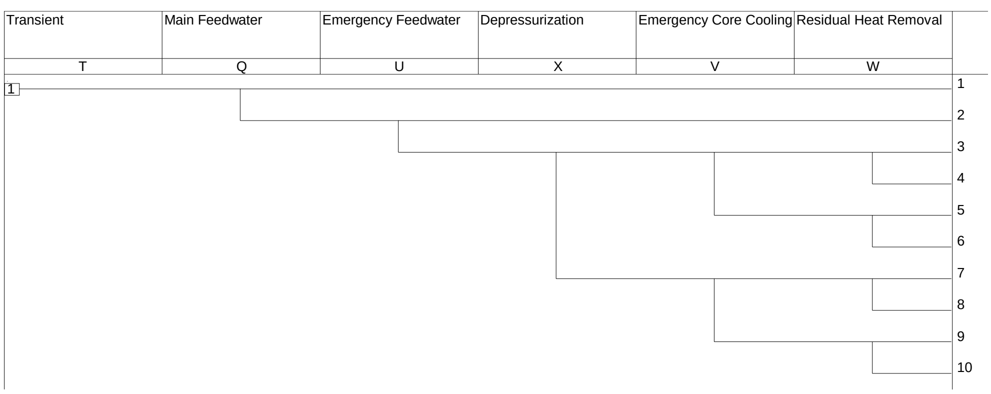
Accident Sequence Models : Event Trees



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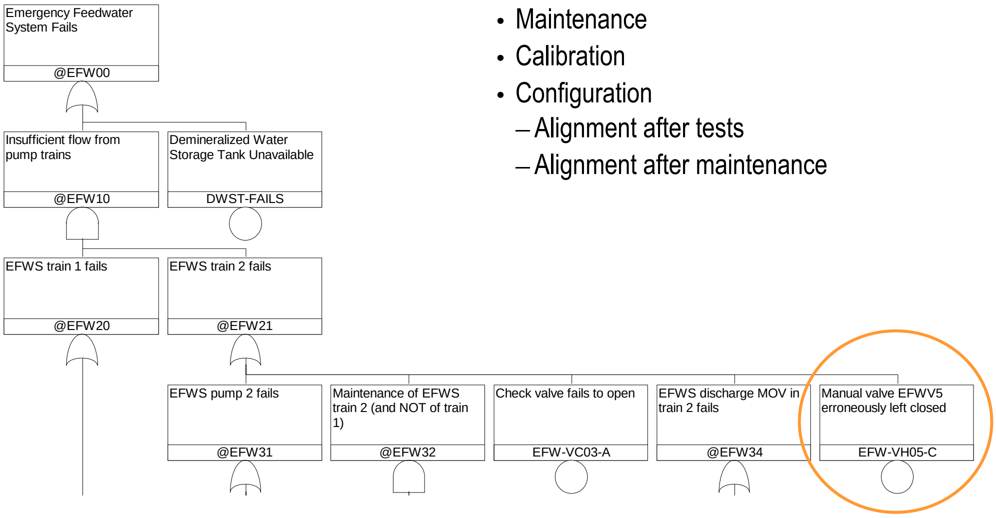
Systems Analyses : Fault Trees



- Maintenance
- Calibration
- Configuration
  - Alignment after tests
  - Alignment after maintenance

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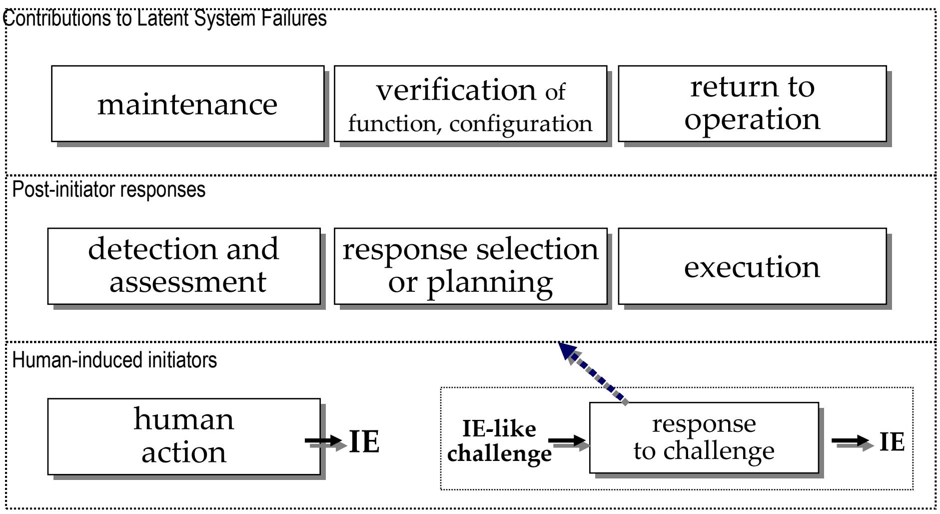
Task Models

by HI Categories (NPP PSAs)



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2.

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Performance Factors and Qualitative Analysis

"ideal" case : statistical data

errors / # performances

Use (prefer) when experience data is sufficient or can be collected.
Tasks that are:
✓Frequently performed
✓Routine and periodic

Challenges

- Lack of observations for **rare situations and tasks**
- Differences in **conditions and context**
- Sensitivity of **decision-related performance** to single factors

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Qualitative Analysis

Characterize key factors, in order to assess, adjust or adapt data

- **What conditions are the same?**
- **What conditions are different?**

Understand likely errors and the factors influencing these

performance-shaping factors (PSFs)

- **key influencing factors**
- **relevant factors depend on task**

- **Factors describe task**
  - **Type of task**
  - **Demands of task**
- **situation**
  - **Environment**
  - **Cognitive**
- **Persons performing task**
  - **Knowledge and training**
  - **Experience**

How to go about it?

- **Observe**
  - performance in the work environment, simulations, exercises
- **Review experience records**
  - maintenance reports, event reports
- **Task analyses**
  - including interviews with workers, supervisors, and training personnel (all levels of expertise)
- **Procedures and design documentation**

Human factors methods for design/evaluation of interfaces and tasks, other methods

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Performance Shaping Factors (PSFs)

Adequacy of time

Human-machine interface and indications of conditions

Procedural guidance

Training and experience

Preceding and concurrent actions

Task complexity

Stress

**for Cat. C actions,
abnormal / emergency response based on procedures,
in control room**

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PSFs

Any factor that influences human performance

Three classes of PSFs

- **external**, i.e. those outside the individual
  (environment, task characteristics, organizational)
- **internal**, i.e those that operate within the individual himself (training, experience, stress)
- **stressors**
  (factors directly affecting mental stress and physical stress:
  task speed and load, fatigue, vibration)

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PSFs (2)

Any factor that influences human performance

PSFs allow **adjustment of estimates** for other situations

- **Combinations** of PSFs determine the reliability of human performance
- All quantification methods try to model PSF effects
- A complication: PSFs may interact (be inter-dependent)

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Quantification : Estimating Failure Probabilities

Identify relevant data

Evaluate data

Expert elicitation to overcome gaps and limitations of data

Synthesize and document

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Sources of Human Reliability Data

Internal event reports	
External event reports	**Qualitative**
Near-miss reports/precursors	**Actual (real)**
Violations	
Maintenance reports	**Expert**
Plant log books	
Interviews with plant personnel	**Quantitative**
Handbooks (NUREG/CR-1278)	**Simulated**
Expert judgment	
Simulators	

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Overview of HRA Quantification Methods

Decomposition or Database Methods

- **Technique for Human Error Rate Prediction (THERP)**
- **Accident Sequence Evaluation Program HRA Procedure (ASEP)**
- **Human Error Assessment and Reduction Technique (HEART)**

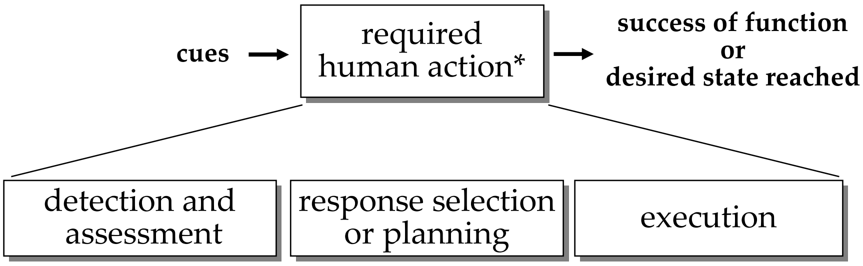
Time-dependent Methods

- **Time Reliability Curves (TRCs)**
- **Human Cognitive Reliability Model (HCR)**
- **HCR/Operator Reliability Experiments (HCR/ORE) Method**

Expert Judgment Based Methods

- **Absolute Probability Judgment (APJ)**
  (Direct Numerical Estimation-DNE)
- **Paired Comparisons (PC)**
- **Success Likelihood Index Method (SLIM)**

Post-Initiator Responses
(and responses to IE-like challenges)



Modeling of Human Actions for Quantification

Decompose human interactions or tasks into quantifiable elements

These include

- **Errors in reading displays**
- **Detection failures**
- **Errors in following procedures** (reading of written procedures, oral communication of instructions)
- **Errors in manual manipulations** (wrong switch, etc.)
- **Errors in diagnosis (incorrect, incomplete, etc.)**

Represent elements within a logic structure

- **Operator Action Trees (OATs),** for required operator actions in response to a disturbance
- **HRA Event Trees (HRAETs),** to treat the execution of actions

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Technique for Human Error Rate Prediction

An HRA method centered on a database of HEPs for different kinds of human actions in nuclear power plant operation.

NUREG/CR-1278, Swain and Guttman, 1983

Sources

- **experiments, field studies, and performance records** in various industries and military situations
- **adjusted for US NPPs** (ca. 1975 conditions) by experts
- some limited **simulator** experiments and **expert judgment** are the basis for the diagnosis models

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Main THERP Components

Representation
HRA Event Tree

Diagnosis Models
Time Reliability Curves (TRCs)

Errors in Execution
Omission and Commission (Tables)

Dependence Model

Adjustments for **Performance Shaping Factors** (PSFs)

THERP guides the analyst
to decompose a human interaction systematically
into component tasks for which
basic HEPs are available in the database.

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THERP Errors in Execution (3)

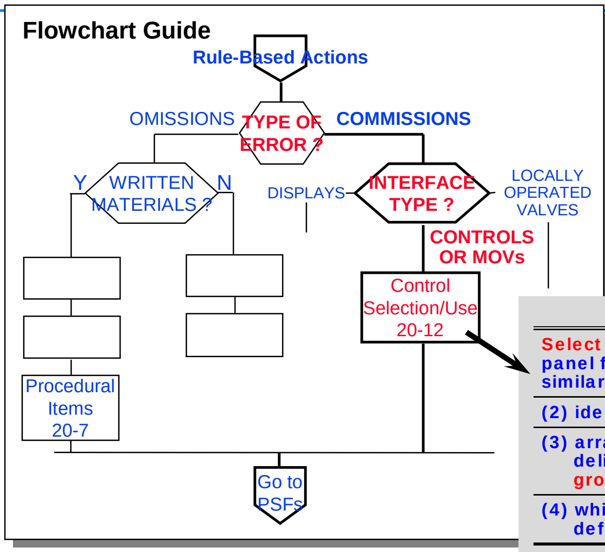

Table 20-12 (excerpt)

	HEP	EF
Select wrong control on a panel from an array of similar-appearing controls**:		
(2) identified by labels only	0.003	3
(3) arranged in well-delineated functional groups	0.001	3
(4) which are part of a well-defined mimic layout	0.0005	10
Turn rotary control in wrong direction...		
(5) ...		

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"1st Generation" analyses of decision-making can be reduced to the following questions:

detection and assessment | response selection or planning | execution

Detection

Are the cues and indications available and salient (HMI)?

Do the operators perceive the information (task load, focus)?

Is there adequate time?

Diagnosis

Do the operators have the training and knowledge to make the appropriate assessment?

Are procedures available for this specific scenario?

Decision

Do procedures support (or detract from) the required decision?

Can the operators reach the decision in time?

Skill-, Rule-, Knowledge- Based Performance

Skill - automated, tasks that are well-learned, practiced

Rule - familiar work situations, relatively automated cognitive behavior.

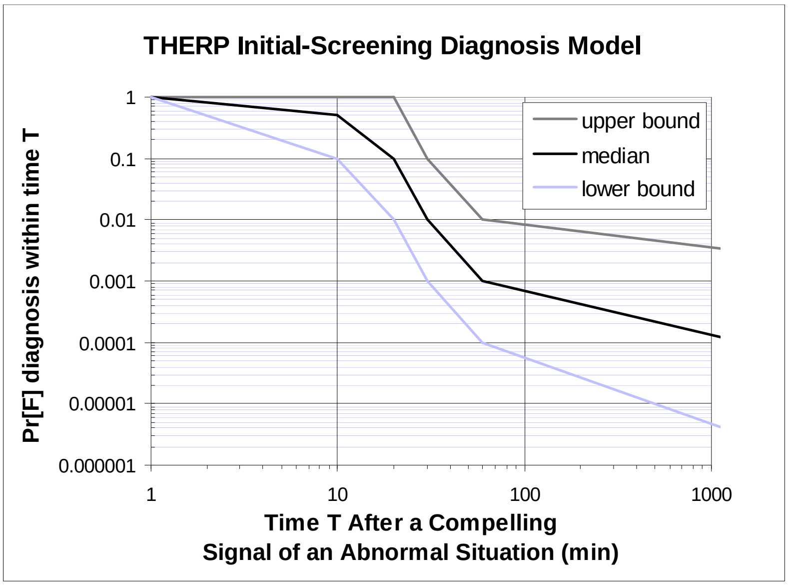
Conscious coordination of skilled tasks.

Knowledge - less familiar situations, when **problem solving and planning** is necessary

When rules are not available or their applicability is uncertain.

Detailed reasoning involving knowledge of basics

Diagnosis Model THERP (2)



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Using the Diagnosis Model

1. Calculate the maximum time available Tm
2. Identify the actions required to successfully cope with the abnormal event, given a correct diagnosis has been made.
3. Calculate the time to perform the required actions Ta.
   When task analysis/simulation data are not available:
   - Use 1 minute for the required travel and manipulation time for each control action in the control room taken on primary operating panels.
   - Use 2 minutes for each control actions on other than the primary panels.
4. Calculate the allowable time for diagnosis Td

$$Td = Tm - Ta$$

5. Use the median curve. If recognition of the situation can be classified as skill-based, use the lower bound curve.

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HRA Quantification

adjustments are needed
- when performance conditions do not match the data
- estimates for average conditions vs. specific scenarios

execution

- algorithms based on expert judgment (THERP execution, SPAR-H)
- expert judgment, structured expert judgment (SLIM),
- *performance-shaping factors (PSFs)*
- validations show this works reasonably well

diagnosis / decision-making performance

- many factors
- non-linear: can be quite sensitive to single factors, case-by-case
- statistical approaches, or "anchor & adjust", not very workable or robust

principal approach has been Time Reliability Curve (TRC)
- THERP TRC
- later, HCR, HCR/ORE
- today, context viewed as driving performance for many decision tasks

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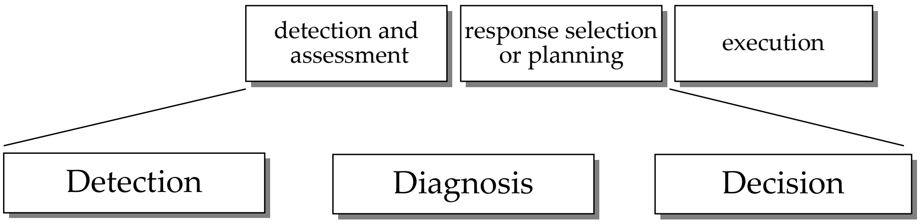
These conditions are minimum conditions



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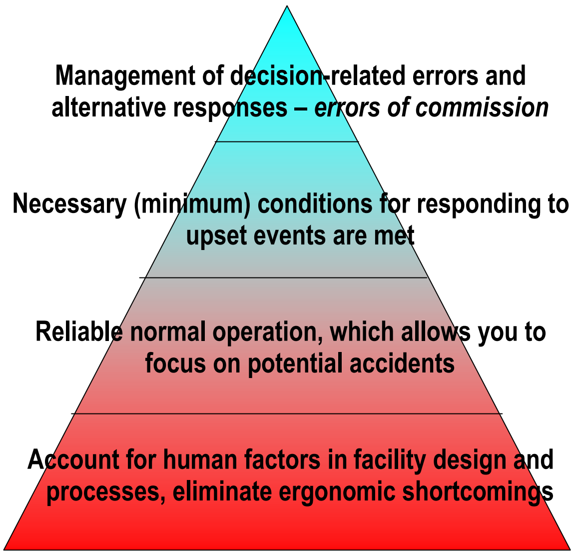

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Identification and Selection

Human influences on system operation include

- **Normal operation** : control actions
- **Maintenance** actions : service, inspection, test, etc.
- Control of **small disturbances** in "abnormal" operation
- **Termination of the development of a disturbance :** reach a safe state
- **Mitigation** of consequences of a disturbance

Planned human actions
- guided by procedures
- addressed in training

Unplanned actions
- usually not credited in a PSA
- develop a plan

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Human Reliability Analysis (HRA)

Identify **actions to model**	**What are the likely and/or important actions and potential errors?**
Qualitative **analysis**	**What influences the performance of these tasks?**
Quantification	**Estimate human error probabilities (HEPs)**
Review of results **by domain experts**	Ensure credibility and acceptance
Integration **in PSA**	Add to or modify accident sequence and system models

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Human Error (HE)

"any member of a set of human actions that exceeds some limit of acceptability… out-of-tolerance action, where limits of tolerable performance are defined by system" *

"divergence between the action actually performed and the action that should have been performed" **

- **system-based and PSA-based perspective**
- **Note: an action required, e.g. by procedures, in the given situation can be a HE (HFE) from the PSA perspective!**

Human Failure Event **(HFE) is generally preferred today – more neutral term**

*** NUREG/CR-1278 A Technique for Human Error Rate Prediction**
**** NUREG/CR-6350 A Technique for Human Error Analysis (ATHEANA)**

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Identification of actions

Top-down

In Accident Sequence Modeling

Scenario by scenario, what are the required personnel interventions?

In Systems Analysis

What maintenance, testing, and other operations could disable a system?

Bottom-up

Selective

Task analysis

Human error analysis (HEA)

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Screening

1. Screening on basis of contribution to PSA

- HEP assignments of 1.0 / 0.5 / 0.1
- provides structural information on PSA

2. Screening values

- conservative values, not based on a detailed analysis
- should clearly bound actual probabilities (upper bound)

- ➢ **important to distinguish among these types of screening values (1,2) and values supported by a quantitative analysis**
- ➢ **contributors identified as important (F-V, RAW) should be addressed in subsequent detailed analyses**
- ➢ **RAW identifies actions for which unforeseen contributions would have largest impact**

5.

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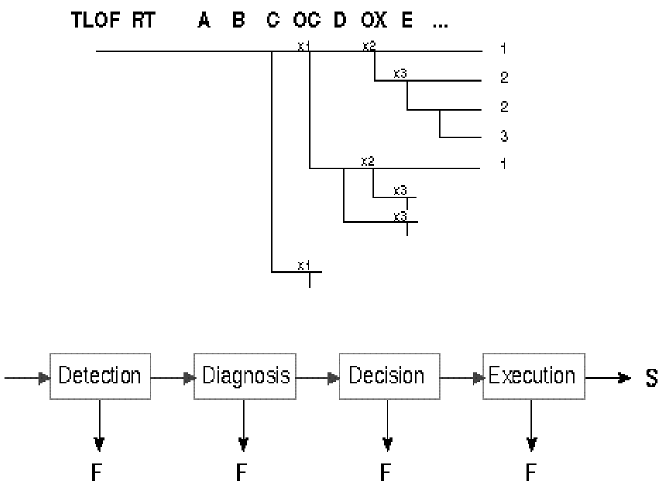
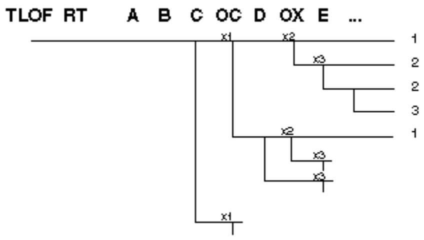
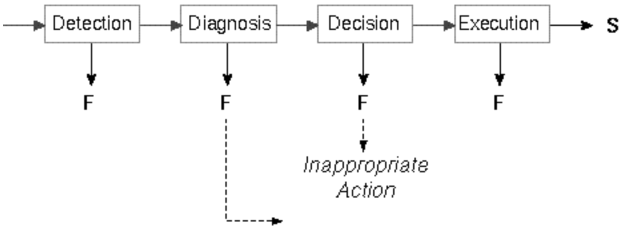
Decomposition of Cat. C Actions



Decision / Diagnosis Failures Impact Subsequent Performance





Dependence

HEP(task N) given failure of task N-1

Within-task dependence
- Individual, team or crew

Between tasks
- Overall understanding of situation (situation assessment) relevant to several tasks
- Between recognition that a function needs to be assured (cognitive performance) and options for this function
- Among execution, error correction, and recovery of task or of function
- Same person/team execute multiple tasks

THERP Dependence Model
- Zero, low, moderate, high, complete
- Positive dependence credited only exceptionally

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Dependence (example):

Impact on combination of HEPs

HEP_{n-1}	HEP_n | $task_{n-1}$ failed		*Performance for combination* HEP_{n-1} x HEP_n
0.005	Zero (Independent)	0.001	**5.E-6 !**
	Low	0.05	2.5E-5
	Medium	0.14	0.0007
	High	0.5	0.0025
	Complete	1.0	**0.005**

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Some Criteria for Dependence

Assess some level of dependence for tasks
- **close in time**
- **same system or function**
- **same procedures**
- **same people**

Independence may be justified if
- **time separation, especially different phases of scenario**
- **different systems**
- **different objectives**

But careful!
- Set criteria for **maximum credit**
  - **Probabilistic criterion**: maximum credit for **combined** post-initiator failure probabilities. Typically used cut-off values range from 1.E-6 to as high as 1.E-4.
  - **Number of failure events** (post-initiator) in a given cut-set
- **Humans don't suddenly get smart**
- **1.E-5 is one failure in 100 000 performances**

Human Performance Limiting Values

Lower bounds

Used as a check on the overall value
Do not use these as assessed values!

single operator performing task	**1E-3**	**(1E-4)**
human "system"	**1E-4**	**(1E-4 – 1E-5*)**
human system with demonstrable relations of independence among personnel	**1E-5**	**(1E-5)**

human "system": operator + supervisor, two shifts
(*values*): nuclear power plants since 1980, plants designed or re-designed with "higher" standards for ergonomics
* use 1E-4 unless exceptional procedures and checks can be documented

cf. Kirwan, 1994

HRA – key points

The qualitative basis is essential

- Involve domain experts, observe performance in actual work environment.
- Analyze beyond the scope of the HRA quantification methods. Aim for qualitative insights.

Allocate analysis resources based on risk

- Aim is not a comprehensive review of human factors in maintenance and operations.
- Systematic examination of abnormal and emergency responses.

Collect, analyze and use the available data

- Complement databases and generic data with your performance data
- Account for facility-, task-, and scenario-specific PSFs

Dependence and limiting values

- 1E-5 is one failure in 100'000 performances

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Why HRA?

Analysis and quantification of human interactions and failures within the assessment of **risk and risk contributors**

- Human actions contribute significantly to plant risk, but also to safety
- Necessary for understanding accident sequences and their relative importance to overall risk

Identify weaknesses in system design or configuration

Reduce the consequences of human failures

May provide **insights to improve human performance**

- Improve the human-machine interface
- Identify potential situations with conflicting objectives
- Increase chances of recovery
- Improve procedures

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Thank you for your attention !

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