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JAEA

Human Factors and Ergonomics in Nuclear Reactor

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FTC Reactor Engineering,
KST BJ Habibie, 20 February 2025

Outlines

1. Introduction
2. The Scope of Human Factors and Ergonomics
3. HF Implementation in the Nuclear Reactor and HMI Design
4. Human Error and Human Reliability
5. Resume

1. Introduction

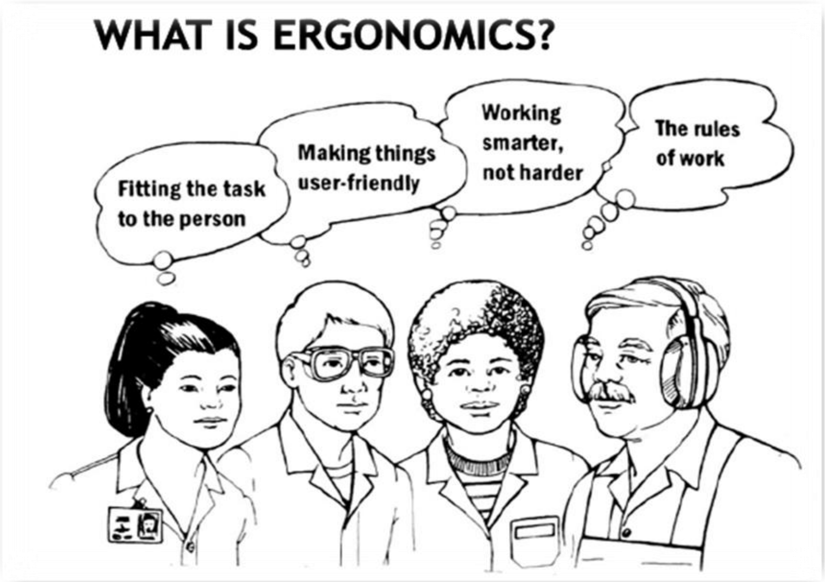
Contribution of human error to the occurrence of events (courtesy of the USDOE):
IAEA Nuclear Energy Series, No. NG-T-2.7: Managing Human Performance to Improve Nuclear Facility Operation, 2014

TABLE 1. LEVELS OF PERFORMANCE IMPROVEMENT

Level	Goals	Key performance tools	Principal management level
Organizational level	Organization goals	Strategies, design/structure, allocation of resources	Executives/senior managers
Process level	Process goals	Process improvement and effective teamwork	Middle level managers
Job level	Job goals	Job design, coaching, performance management and training	First-line supervisors and workers

In order to fully understand how human performance can be managed to facilitate performance improvement, three levels of performance need to be considered: organizational, process and job levels.

1. Introduction



- ✓ Derived from two Greek words:
- ✓ "Nomoi" meaning natural laws
- ✓ "Ergon" meaning work

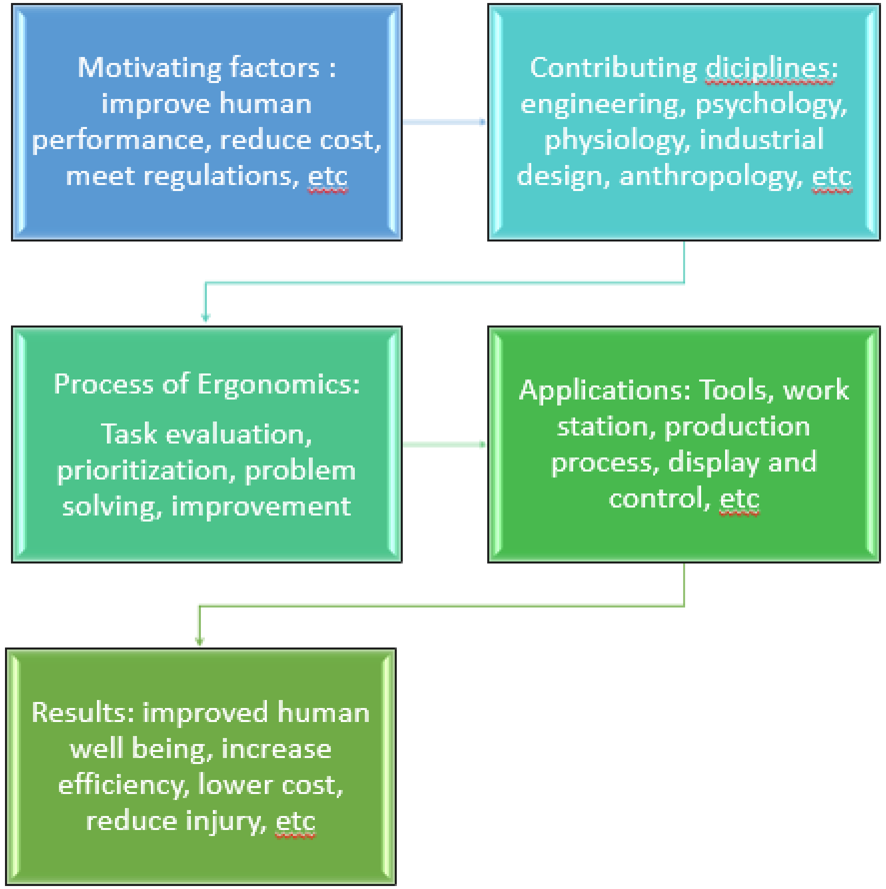
→ergonomics: study human capabilities in relationship to work demands

" Ergonomics is the application of scientific information concerning to the design of objects, systems and environment for human use."

The Institute of Ergonomics and Human Factors 2010

2. The Scope of Ergonomics

- **Organizational ergonomics**: Focuses on designing inclusive work systems
- **Physical ergonomics**: Focuses on physical activity, safety, posture, and injury risk reduction
- **Cognitive ergonomics**: Focuses on mental processes like memory, perception, and reasoning
- **Environmental ergonomics**: Focuses on how heat, cold, vibration, noise, odor, and light affect people's health, comfort, and performance
- **Applied ergonomics**: Focuses on fitting workspaces to people's needs

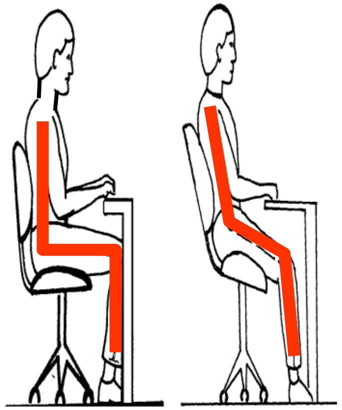


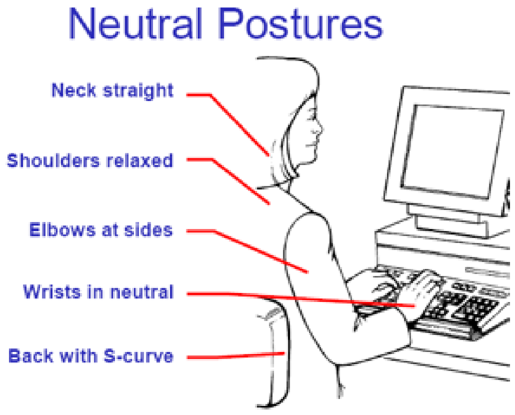
2. The Scope of Ergonomics

Design of working place and environment

Twelve simplified principles :

1. Work in neutral posture
2. Reduce excessive forces : grasping, push and pull, etc
3. Keep everything in easy reach
4. Work at Proper Heights
5. Reduce excessive motions
6. Minimize static load
7. Minimize Pressure Points
8. Provide clearance
9. Maintain a comfortable environment
10. Make displays & controls understandable
11. Reduce Stress
12. Move, Exercise & Stretch





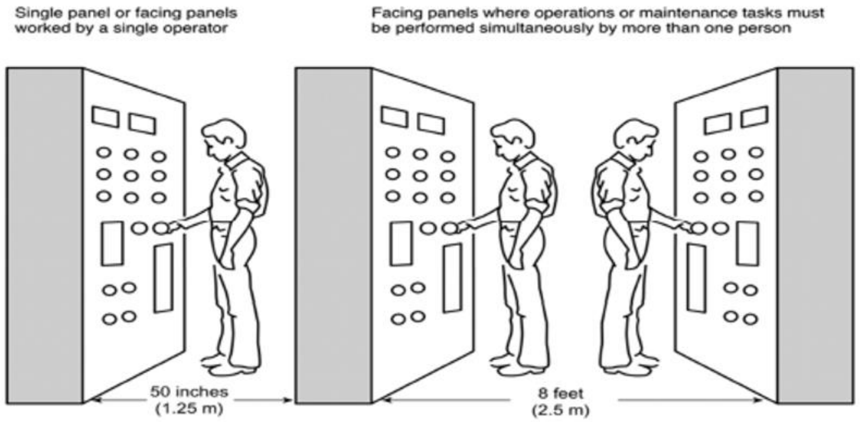
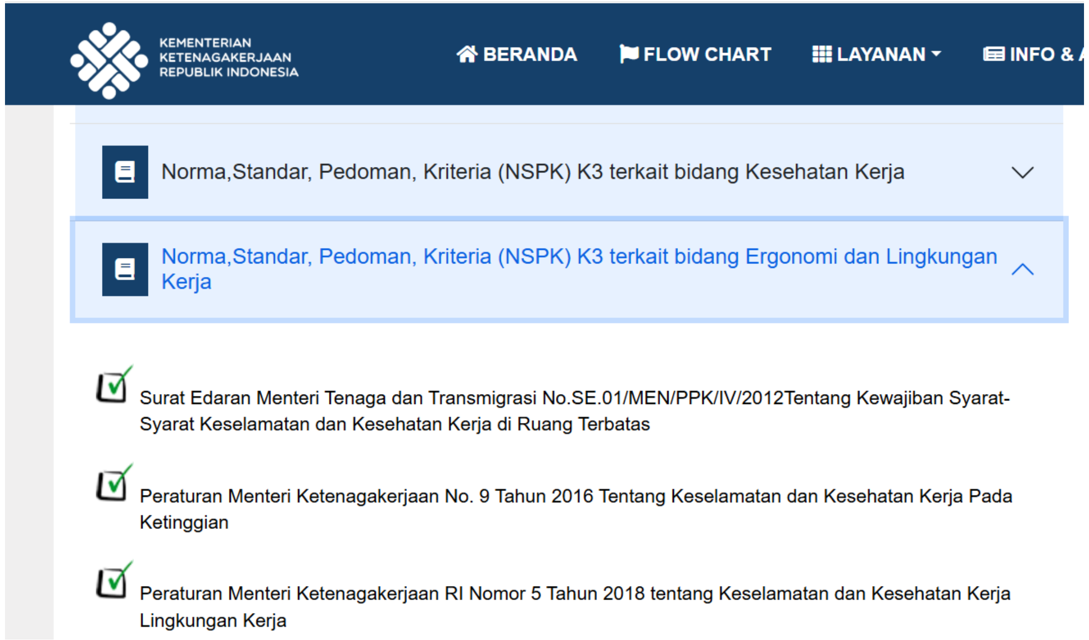


Figure 3-32. Equipment-to-equipment distances

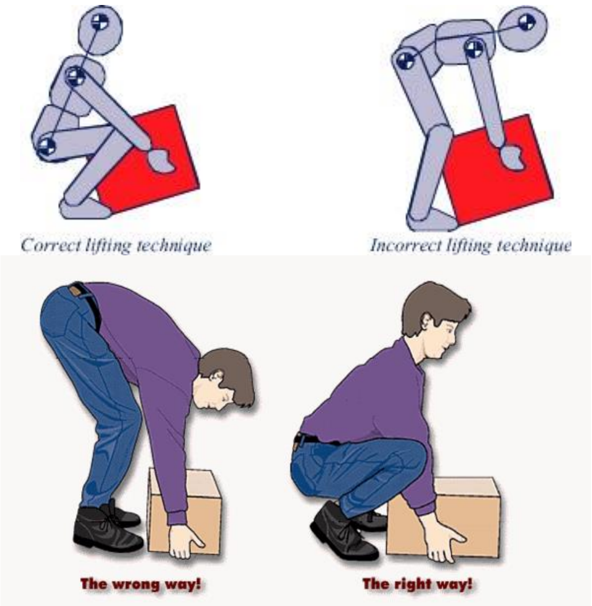
2. The Scope of Ergonomics and Human Factors

Keselamatan dan Kesehatan Kerja (K3), HSE (Health, Safety and Environment)



- Peraturan Menteri Ketenagakerjaan RI Nomor 5 Tahun 2018 tentang **Keselamatan dan Kesehatan Kerja Lingkungan Kerja.**
- K3 adalah segala kegiatan untuk menjamin dan melindungi keselamatan dan kesehatan Tenaga Kerja melalui upaya pencegahan kecelakaan kerju dan penyakit akibat kerja.
- **Faktor ergonomi** adalah faktor yang dapat mempengaruhi aktivitas tenaga kerja, disebabkan oleh ketidak sesuaian antara fasilitas kerja yang meliputi cara kerja, posisi kerja, alat kerja, dan beban angkat terhadap tenaga kerja.

2. The Scope of Ergonomics and human factors



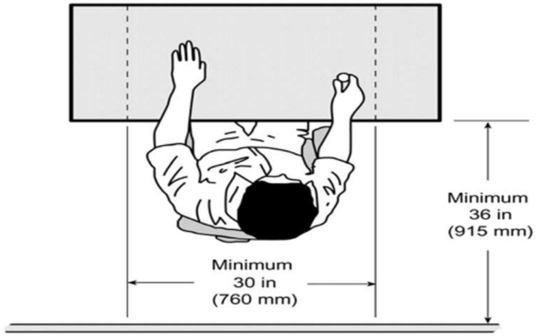


Figure 3-31. Spacing of equipment to accommodate seated users

The design of work place/work station should consider on the **anthropometric data, stereotype population**

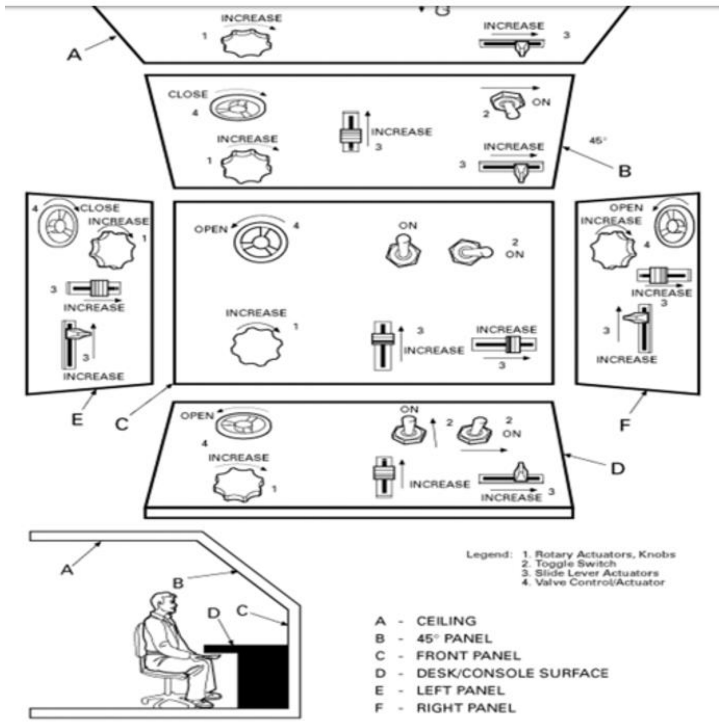
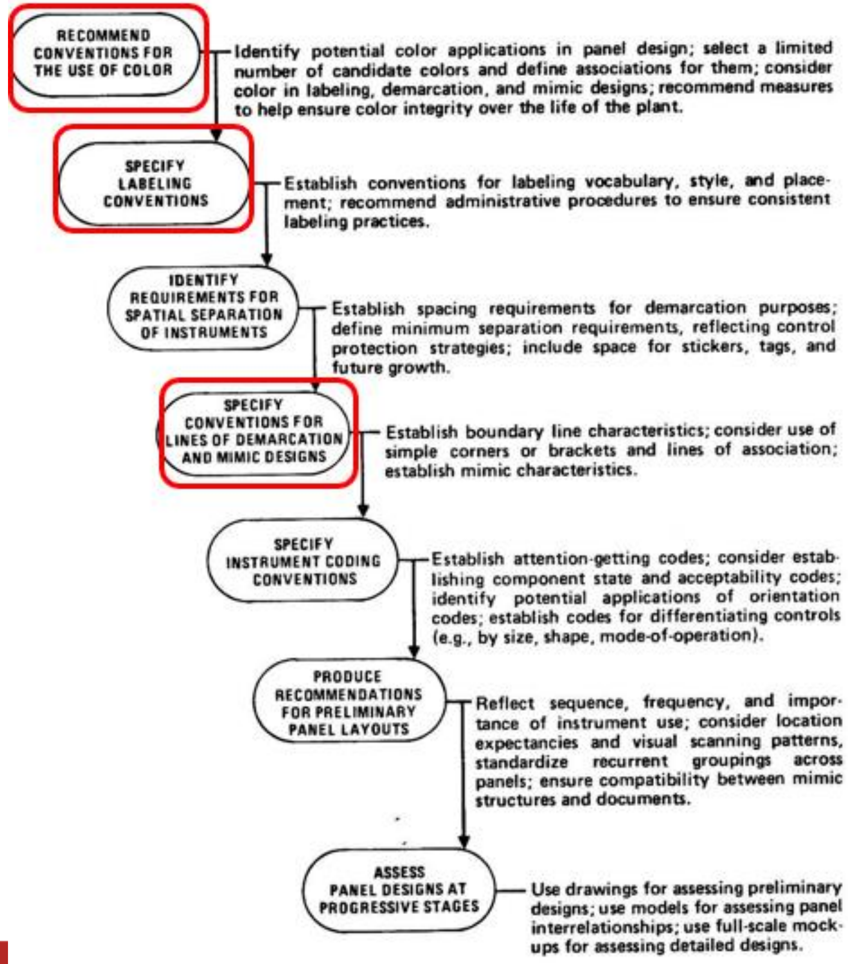


Figure 3-35. Control operation stereotypes for the U.S. population

2. The Scope of Ergonomics and Human Factors

Panel design: requirement and standard



BACKGROUND COLOR	CHARACTER COLOR
White	Black
Dark blue	Yellow
Green	White
Light gray	Black
Dark gray	White
Red	White

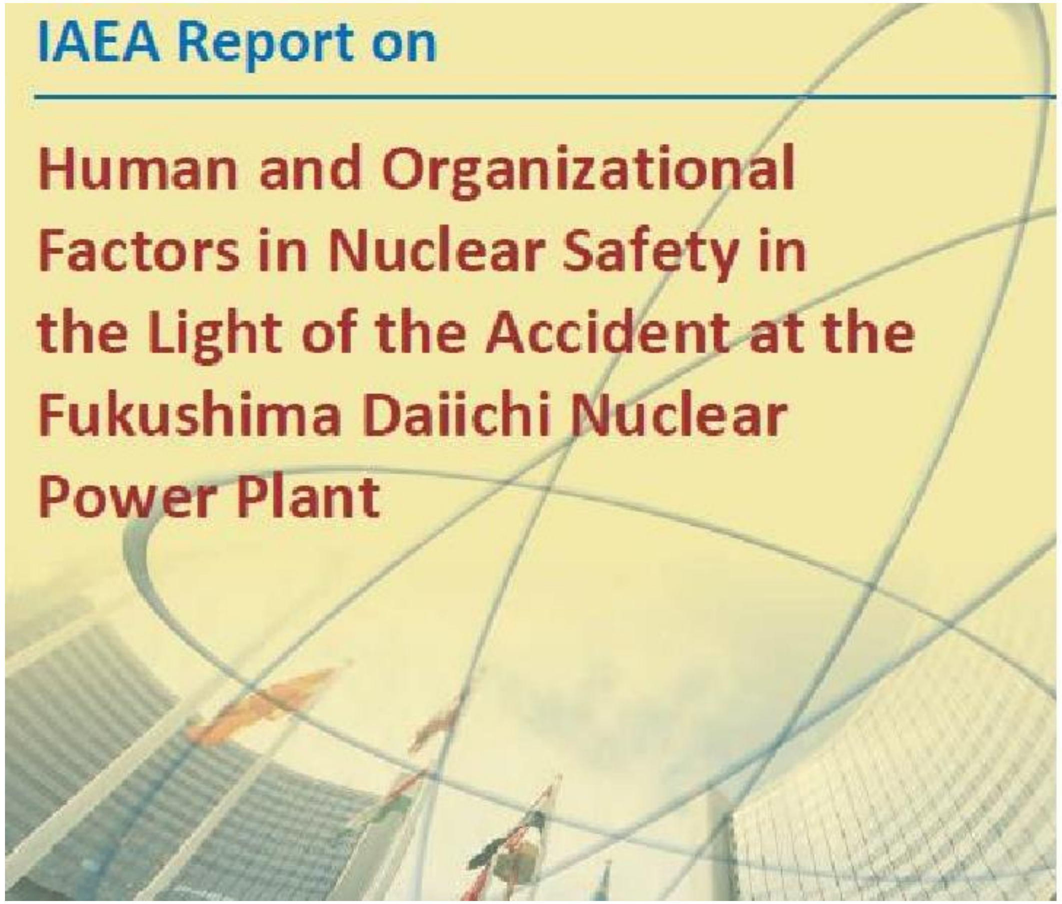
Exhibit 4-28. Combinations of label background and character colors that produce good legibility (Mil-STD-1472C, U.S. Army Missile Command, 1981).

VIEWING DISTANCE (in feet)	CHARACTER HEIGHT (in inches) MINIMUM	PREFERRED
2	.096	.144
3	.144	.216
4	.192	.288
5	.240	.360
6	.288	.432
10	.480	.720
20	.960	1.440
25	1.200	1.800

Note. — Under unfavorable illumination conditions or for especially critical markings, preferred values become minimum design values.

Exhibit 4-32. Recommended character heights for selected viewing distances.

3. HF implementation in Nuclear Reactor



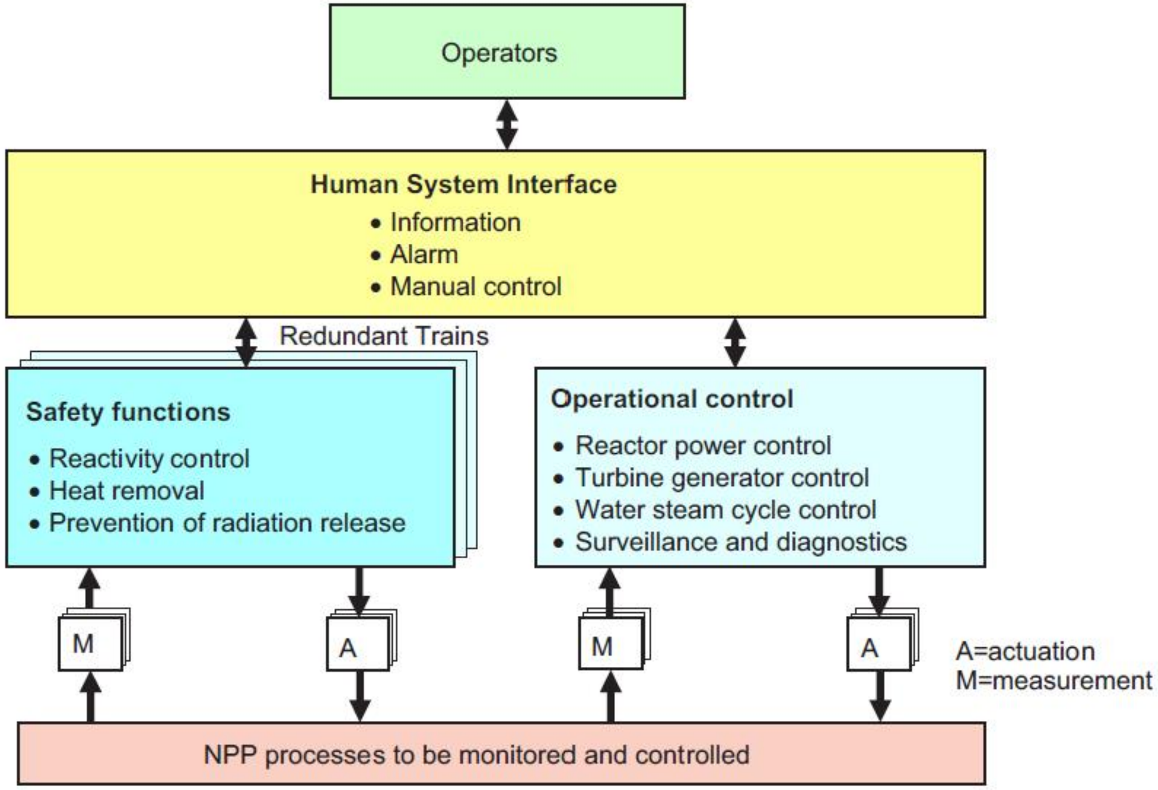


FIG. 5. Functional overview of NPP I&C.

3. HF implementation in Nuclear Reactor

- **Convention on Nuclear Safety (CNS):**

"Each Contracting Party shall take the appropriate steps to ensure that the capabilities and limitations of human performance are taken into account throughout the life of a nuclear installation."

- **Safety Fundamentals:**

"To prevent human and organizational failures, human factors have to be taken into account and good performance and good practices have to be supported"

3. Implementation in Nuclear Reactor

- CONCEPT: Application of knowledge about human capabilities and limitations to reactor plant, system, and equipment design.
- OBJECTIVE: Ensure that the equipment design (e.g. Human System Interface/HSI), the human tasks and the work environment are compatible with the **cognitive and physical attributes** of the personnel who operate, maintain and support the Reactor Plant.
- Human Factors /Ergonomics is not only a licensing requisite, but also a way **to ensure that the plant can be operated safely** while taking into account mental and physical human limitations.

3. Implementation in Nuclear Reactor

Elements of Human Factors Program

- Organizational and management structures, policies and programs
- Allocation of functions between humans and automation
- User interface design
- Staffing and job design
- Shift work systems
- Design of written procedures
- Physical work environment
- Human reliability
- Safety Culture
- ...

3. Implementation in Nuclear Reactor

HF Standards and Requirements

Perka BAPETEN Nomor 3 Tahun2011 : Ketentuan Keselamatan Desain Reaktor Daya

- **Persyaratan Umum** : Reaktor Daya harus didesain dengan mempertimbangkan faktor manusia termasuk antarmuka manusia-mesin
- **Persyaratan Khusus** : Desain Sistem I&K dan ruang kendali reliable untuk semua kondisi operasi

HF Standards and Requirements

- **PERKA BAPETEN Nomor 3 Tahun2011 : Ketentuan Keselamatan Desain Reaktor Daya**
- Persyaratan Umum desain untuk faktor manusia (Pasal 31):

- Reaktor Daya harus didesain dengan mempertimbangkan faktor manusia termasuk antarmuka manusia-mesin.
- Desain mempertimbangkan :

  a. jumlah minimum personil pengoperasi;

  b. tata letak instalasi, tata letak peralatan, dan prosedur yang memudahkan interaksi antara personil pengoperasi dan peralatan di semua kondisi instalasi;

  c. antarmuka manusia-mesin yang dapat menyediakan informasi secara komprehensif dan mudah diolah untuk digunakan dalam pengambilan keputusan dan tindakan;

  d. faktor psikologi personil pengoperasi;

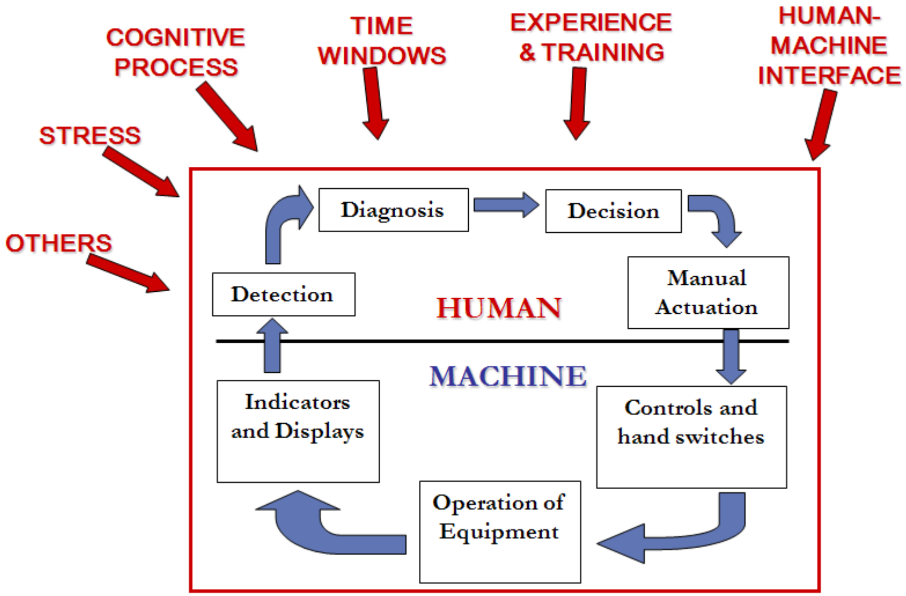
  e. perlindungan keselamatan personil pengoperasi di ruang kendali, ruang kendali tambahan, dan jalur akses ke ruang kendali tambahan dalam hal terdapat kejadian yang berdampak ke instalasi;

  f. konsep ergonomi dalam desain daerah kerja dan lingkungan kerja; dan

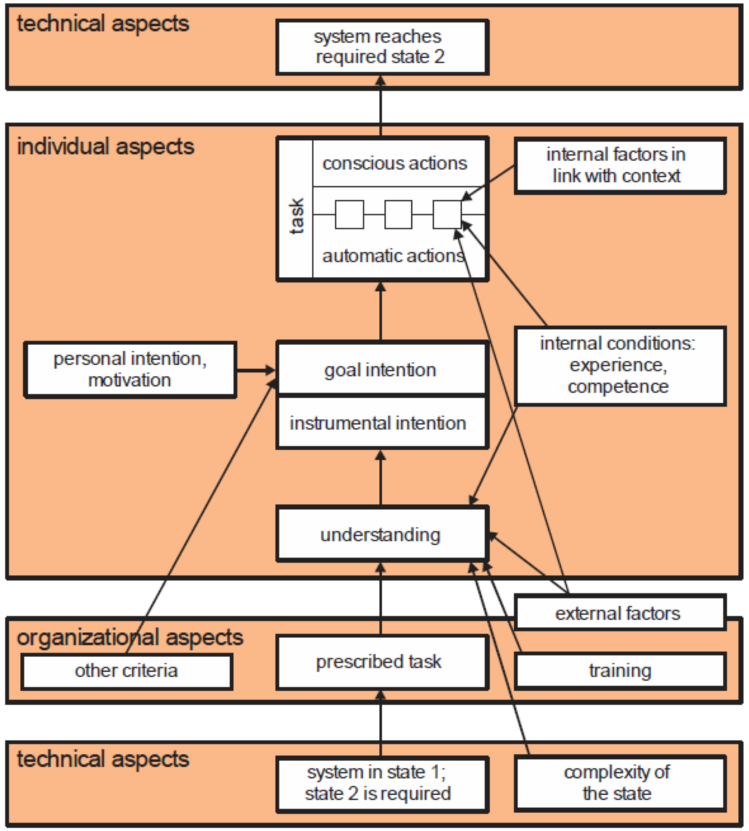
  g. verifikasi dan validasi fitur terkait dengan factor manusia, termasuk dengan menggunakan simulator.

3. Implementation on the Nuclear Reactor

Control Room and HMI Desain

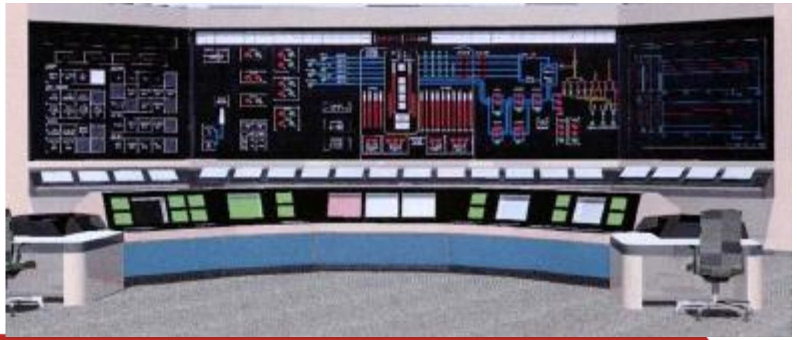


HMI Design: enhancing reactor plant operation safety by providing reactor operator with more suitable and appropriate HMI components



3. Implementation in the Nuclear Reactor
Control Room and HMI Desain

Design of Main Control Room for Nuclear Power Plant



3. HF Implementation in Nuclear Reactor

Control Room and HMI Desain : generic process

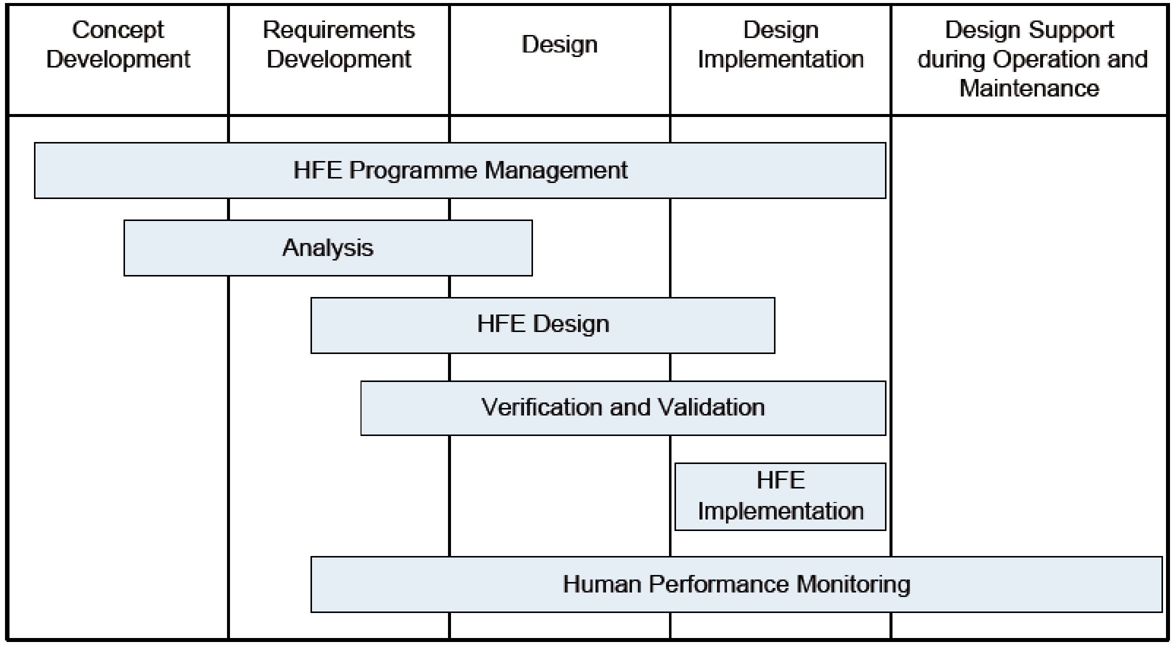


FIG. 1. An example of a generic engineering project, indicating when human factors engineering (HFE) activities are undertaken.

Requirement 32 of SSR-2/1 (Rev. 1) [1] states: "Systematic consideration of human factors, including the human–machine interface, shall be included at an early stage in the design process for a nuclear power plant and shall be continued throughout the entire design process."

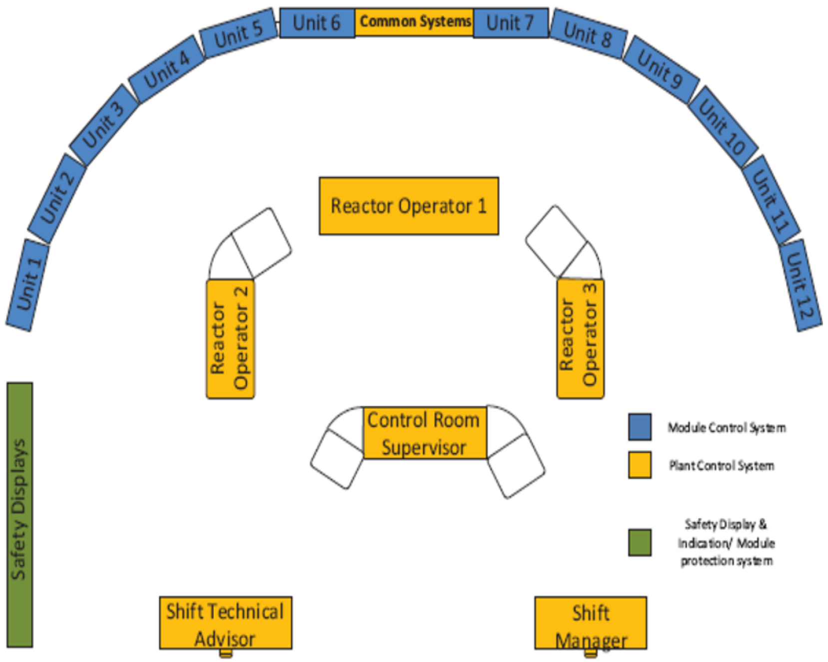
3. Implementation in the Nuclear Reactor

Human Factors Program

- **Human Factors (HF) Programs** are one of the safety areas/elements considered by regulators →Regulatory requirements/guidance and criteria should exist
- **Establishment of HF program** should be supported with adequate Human Performance programs
- IAEA Safety Standards do not prescribe the elements of HF program. There is a general consensus regarding the elements of a HF program, **but regulatory requirements are International Atomic Energy Agency country specific**

3. Implementation on the Nuclear Reactor

Control Room and HMI Desain



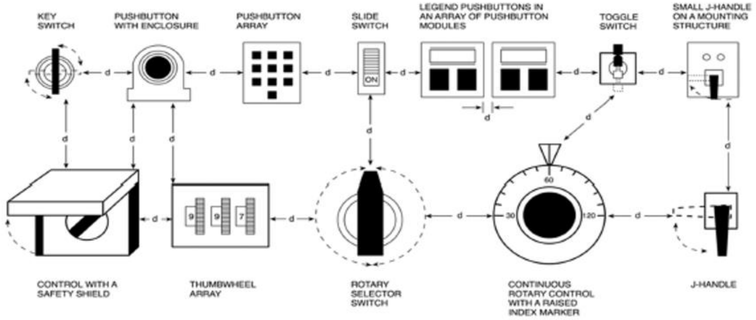


Figure 3-30. Measurement of minimum separation between controls

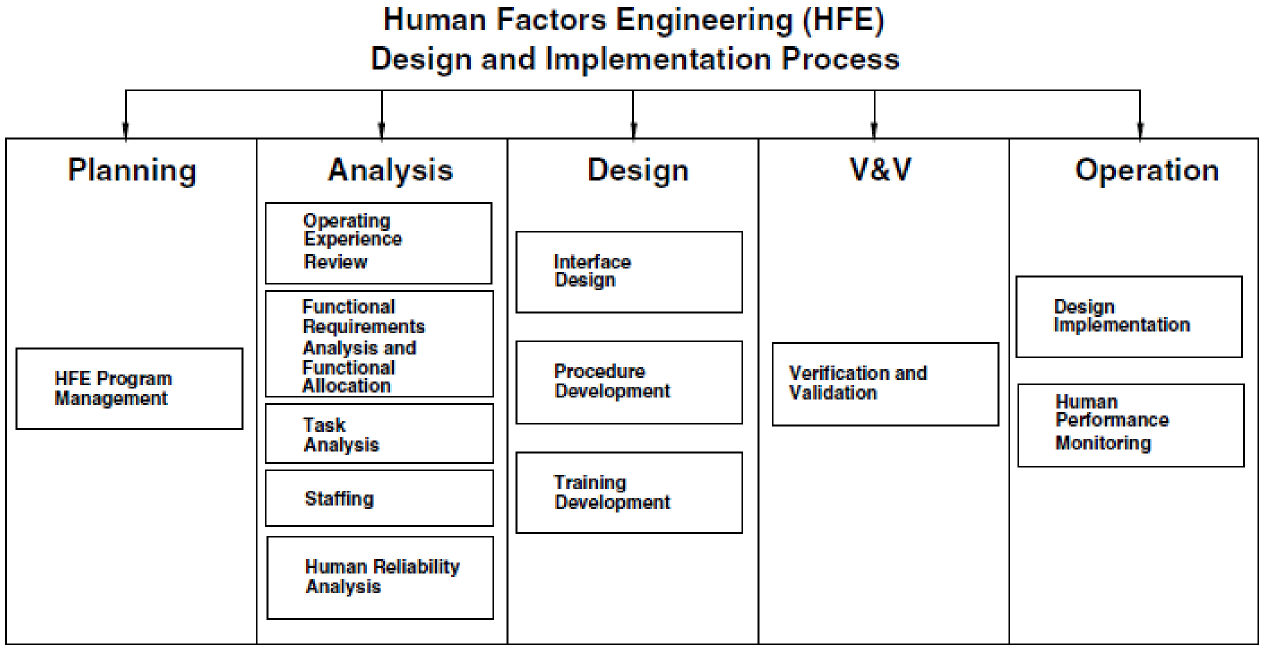
3. Implementation in Nuclear Reactor

Control Room and HMI Desain

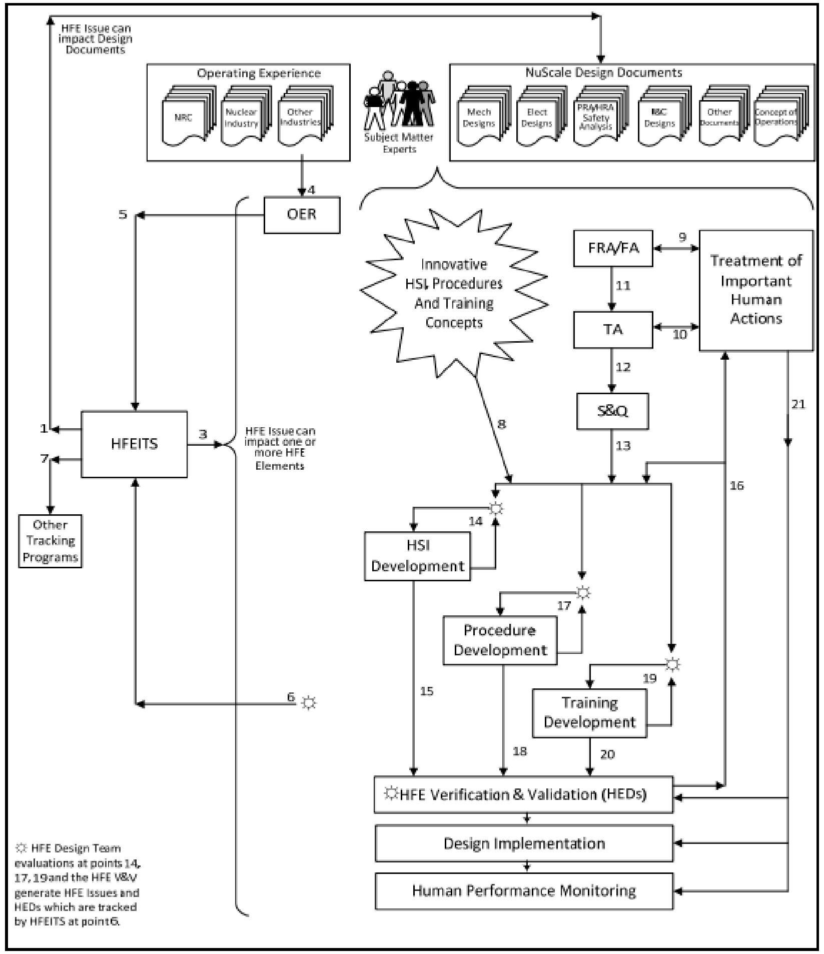
- Iterative approach in the design process of the human-machine interface.
- Final Safety Analysis Report is required to fulfill Nuclear Licensing requirements
- Considers to the standard for the Final Safety Analysis Report (such as NUREG-0800) and associated requirements which specifies with detail all the license requirements regarding Human Factors Engineering

3. HF implementation in Nuclear Reactor

Control Room and HMI Desain



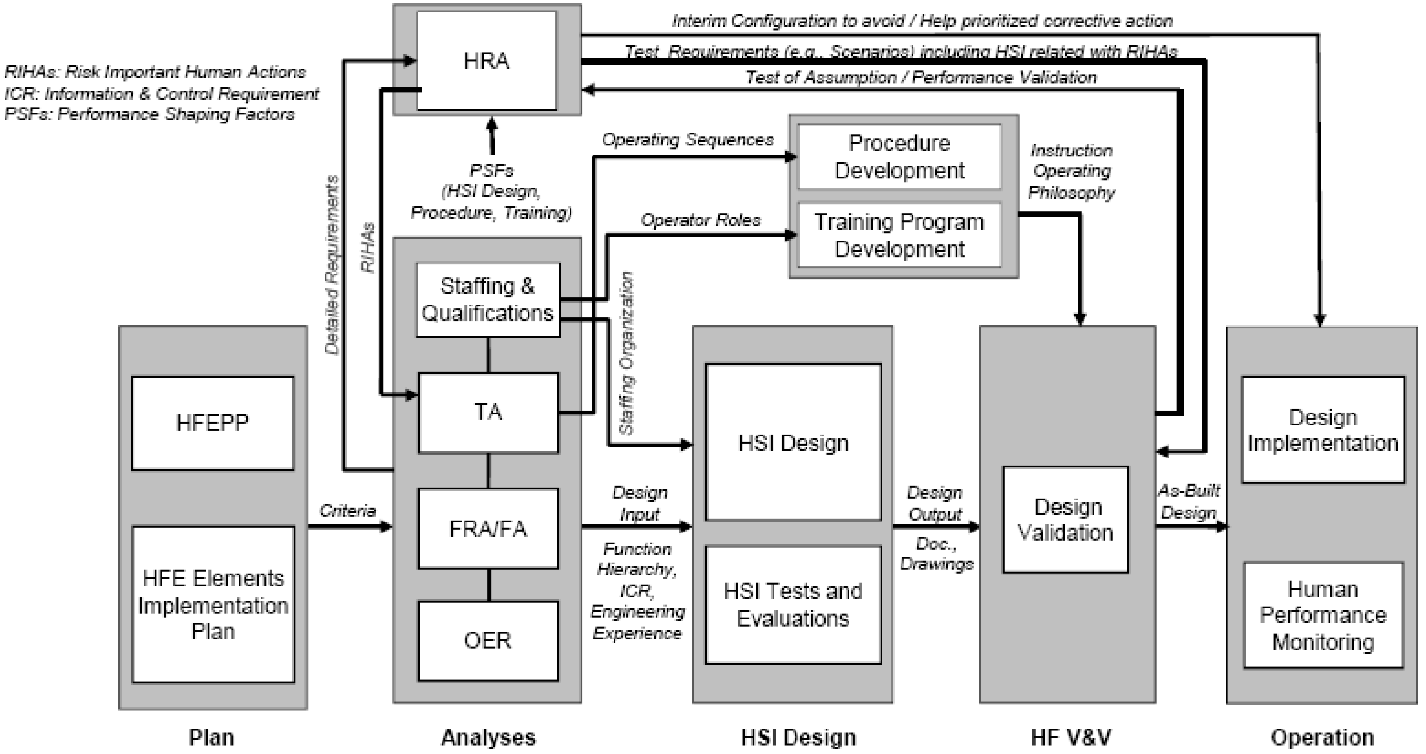
The elements of the human factors engineering program NUREG-0711,



Overview of Human Factors Engineering Program Process at NuScale

3. HF implementation in Nuclear Reactor

Control Room and HMI Desain



HFE program implementation on APR 1400

3. Implementation in Nuclear Reactor

❖ **Human Factors requirements in the Safety Analysis Report (SAR)** :

To identify the how the design has been engineered to account for potential human errors, considering operator capabilities, limitations, and cognitive processes, aiming to minimize the risk of accidents by optimizing interactions between operators and the plant through features like user-friendly interfaces, clear procedures, and workload management.

❖ **Key aspects :**

Operator workload analysis, Control room design, components and layout, Alarm system and procedure development, Training Requirements, HRA

❖ **Regulatory compliance**:

Adhering to relevant regulatory standards and guidelines for human factors engineering in nuclear power plants.

3. Implementation in Nuclear Reactor

Regulatory Requirements


SALINA[N]

KEPALA BADAN PENGAWAS TENAGA NUKLIR REPUBLIK INDONESIA

PERATURAN BADAN PENGAWAS TENAGA NUKLIR
REPUBLIK INDONESIA
NOMOR 11 TAHUN 2020
TENTANG
[PENYUS]UNAN LAPORAN ANALISIS KESELAMATAN REAKTOR DA[YA]
DENGAN RAHMAT TUHAN YANG MAHA ESA

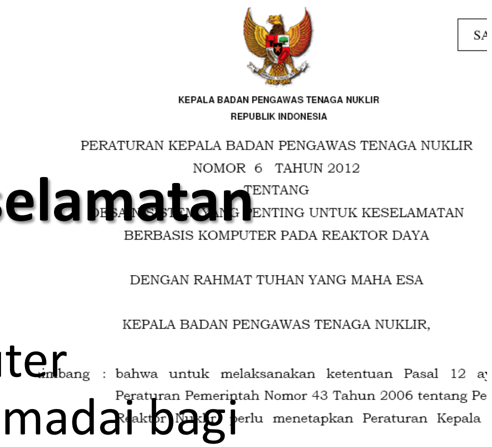
PERATURAN BADAN PENGAWAS TENAGA NUKLIR REPUBLIK INDONESIA NOMOR 11 TAHUN 2020 TENTANG PENYUSUNAN **LAPORAN ANALISIS KESELAMATAN** REAKTOR DAYA. →BAB XIX Rekayasa Faktor Manusia

- Pengelolaan program rekayasa faktor manusia,
- Analisis rekayasa faktor manusia, desain antarmuka manusia dan mesin,
- Verifikasi dan validasi dari hasil rekayasa faktor manusia, implementasi desain, monitoring kinerja manusia.

3. Implementation in Nuclear Reactor

Regulatory Requirements

Perka BAPETEN No 6 Tahun 2012 **Desain Sistem yang Penting untuk keselamatan Berbasis Komputer** pada Reaktor Daya : →


KEPALA BADAN PENGAWAS TENAGA NUKLIR
REPUBLIK INDONESIA

PERATURAN KEPALA BADAN PENGAWAS TENAGA NUKLIR
NOMOR 6 TAHUN 2012
TENTANG
ENTING UNTUK KESELAMATAN
BERBASIS KOMPUTER PADA REAKTOR DAYA

DENGAN RAHMAT TUHAN YANG MAHA ESA

KEPALA BADAN PENGAWAS TENAGA NUKLIR,

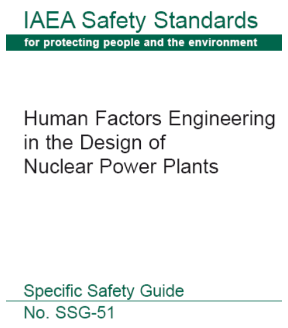
: bahwa untuk melaksanakan ketentuan Pasal 12 a
Peraturan Pemerintah Nomor 43 Tahun 2006 tentang Pe
perlu menetapkan Peraturan Kepala

- ❖ Antarmuka manusia-mesin Sistem yang Penting untuk Keselamatan Berbasis Komputer didesain menyediakan informasi yang memadai dan terstruktur, dan waktu yang memadai bagi operator untuk merespons. Seluruh masukan dari operator divalidasi untuk mencegah kesalahan operator.
- ❖ Penyelesaian Tindakan Protektif : Sistem Keselamatan Berbasis Komputer didesain memerlukan Tindakan operator untuk mengembalikan ke kondisi normal
- ❖ Tampilan Informasi : Perangkat keras Sistem Keselamatan Berbasis Komputer didesain memiliki instrumentasi tampilan yang menyediakan tindakan pengendalian secara manual apabila tidak terdapat pengendali otomatis.

3. Implementation in Nuclear Reactor

Standards and Requirements

- IEC60964 (1989). It is the main IEC standard for the design of the main control rooms of NPP.
- Code on Equipment Design to Prevent Operation Error in Main Control Room (JEAC 4624-2009).
- IAEA SSG-51, Human Factors Engineering in the design of NPP.



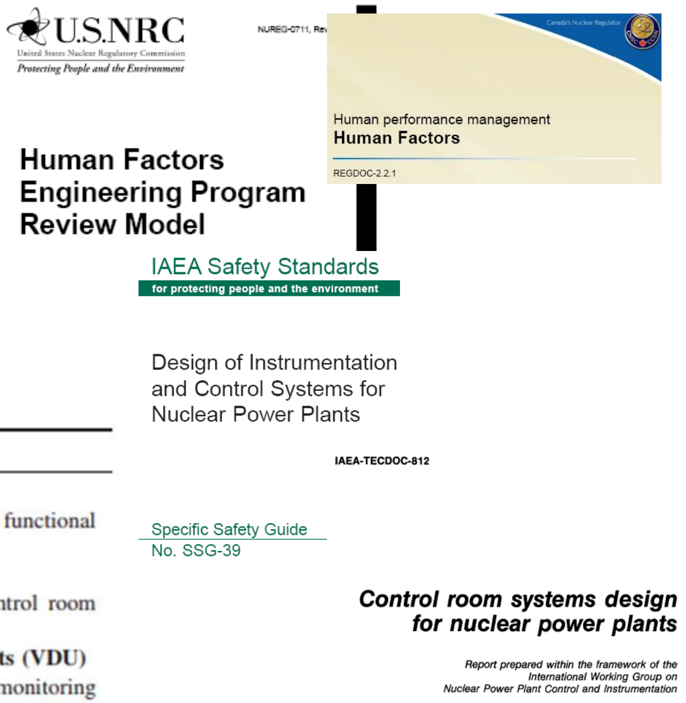


Table 2 Supplemental standards of IEC60964

IEC No.	Title and scope
IEC61227[5]	**Nuclear power plats—Control rooms—Operator controls** This document specifies the standards of operator controls using software. It covers the functional design specification of IEC60964.
IEC61771[6]	**Nuclear power plants—Main control room design—Verification and validation** This document specifies the standards regarding with verification and validation of control room design. It includes the detailed standards than the standards included in IEC60964.
IEC61772[7]	**Nuclear power plants—Main control room design—Application of visual display units (VDU)** This document specifies the standards when VDU is applied replacement or additional monitoring device of conventional hardware instrumentation.
IEC61839[8]	**Nuclear power plants—Design of the main control room—Functional analysis and assignment** This document specifies the detailed functional assignment and procedures.
IEC62241 FDIS[9]	**Nuclear power plants—Main control room—Alarm functions and presentation** This document specifies the detailed standards for alarm signal processing, control, and presentation.

Note FDIS: Final Draft of International Standard, CDV: Committee Draft for Vote

3. Implementation in Nuclear Reactor

Standards and Requirements

ISO11064-1 is the general purposes international standard which defines the human centered design process

Table 3 ISO11064: Ergonomic design of control centres

ISO No.	Title and scope
ISO11064-1[3]	Part 1: Principles for the design of control centres
ISO11064-2[12]	Part 2: Principles of control suite arrangement
ISO11064-3[13]	Part 3: Control room layout
ISO11064-4 (DIS)	Part 4: Workstation layout and dimensions
ISO11064-5 (WD)	Part 5: Displays and controls
ISO11064-6 (CD)	Part 6: Environmental requirements for control rooms
ISO11064-7 (WD)	Part 7: Principles for the evaluation of control centres
ISO11064-8	Part 8: Ergonomics requirements for specific applications

Table 1 Parts of ISO9241and relationship with HCI design activities

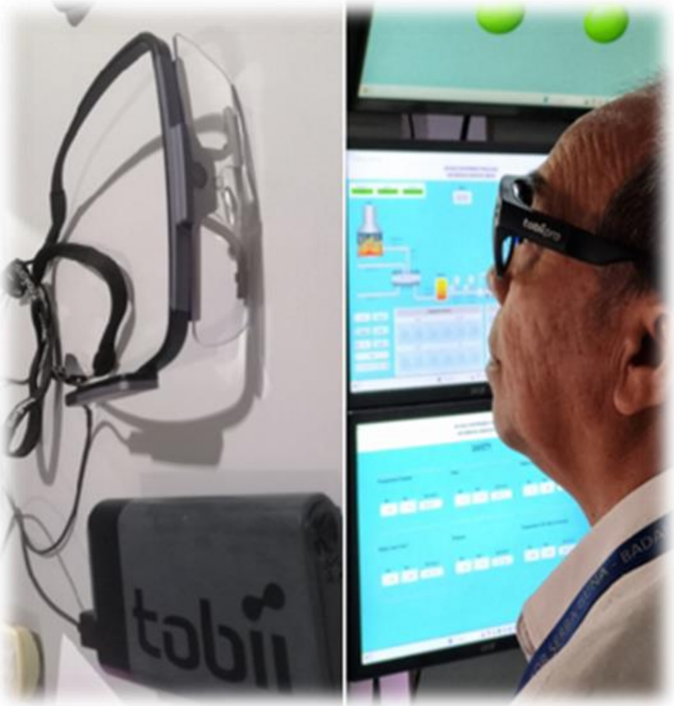
HCI activity	Relevant part of ISO9241	Contents
Analyzing and defining system requirement	ISO9241-11:1998 Guidance on usability	The definition of usability and explanations how to identify the information when specifying or evaluating usability.
Designing user-system dialogues and interface navigation	ISO9241-10:1996 Dialogue principles	General ergonomic principles that apply to the design of dialogues between humans and information systems.
	ISO9241-14:1997 Menu dialogues	Recommendations for the ergonomic design of menus of computer dialogues.
	ISO9241-15:1998 Command dialogues	Recommendations for the ergonomic design of command languages.
	ISO9241-16:1999 Direct manipulation dialogues	Recommendations for the ergonomic design of direct manipulation dialogues.
	ISO9241-17:1998 Form-filling dialogues	Recommendations for the ergonomic design of form-filling dialogues.
Designing or selecting displays	ISO9241-3:1992 Display requirements	Ergonomics requirements for display screens that ensure that they can be read comfortably, safety, and efficiency.
	ISO9241-7:1998 Requirements for displays with reflections	Methods of measurement of glare and reflections from the surface of the screens.
	ISO9241-8:1997 Requirements for displayed colors	Requirements for multicolor displays.
	ISO9241-12:1998 Presentation of information	Specific recommendations for presenting and representing information

ISO9241 : ergonomics of human system interaction

3. Implementation in Nuclear Reactor

Experimental study on the HMI design

Prototipe sistem pegujian HMI: Hardware dan program/aplikasi HMI



- Pre Eksperimen
- Eksperimen

4. HUMAN ERROR AND HUMAN RELIABILITY

“ TO ERR IS HUMAN……”

❖Human Error …is an inappropriate or undesirable human decision or behaviour that reduces or has the potential for reducing the

- ❖effectiveness
- ❖safety
- ❖system performance

https://www.fastcompany.com/

4. HUMAN ERROR AND HUMAN RELIABILITY

Dealing with Human Error

- Human error is inevitable
- Consequences and likelihood can be reduced by:-
  - better recruitment & selection
  - training
  - better design of equipment procedures & work environment
- Tendency to view error at the operator level →1st blame only the individual
- Other people involved in the design and operation of the system can make errors, consider the entire system →2nd identify other factors : -badly designed or faulty equipment, poor management practices, inaccurate or incomplete procedures, etc

WHY DO WE MAKE ERRORS ?

Others

Task complexity :
Error re likely to occur when the task requirements exceed human capacity limitations

Individual differences :
Differences in human abilities and capabilities

Error likely situations:
general situational characteristics that predispose operators to make errors

4. HUMAN ERROR AND HUMAN RELIABILITY

Human Performance Shaping Factors

- PSFs are used in qualitative Human Reliability Analysis (HRA) to identify contributors to human performance. In quantitative HRA, PSFs are often used to derive the HEP.

<table>
<tr><th colspan="2">External PSF</th><th>Internal PSF</th></tr>
<tr><td>Situation
• structure
• environment
• work period
• work shift
……</td><td>Task and tools
• perception
• motion
• procedure
• plant policies
……</td><td rowspan="3">• training
• experience
• skill, attitude
• personality
• intelligence
• motivation
• mentality
……</td></tr>
<tr><td colspan="2">Stressor</td></tr>
<tr><td>Mental
• abruptness
• duration
• task speed
• workload
……</td><td>Physiological
• duration
• fatigue
• discomfort
• hunger, thirst
……</td></tr>
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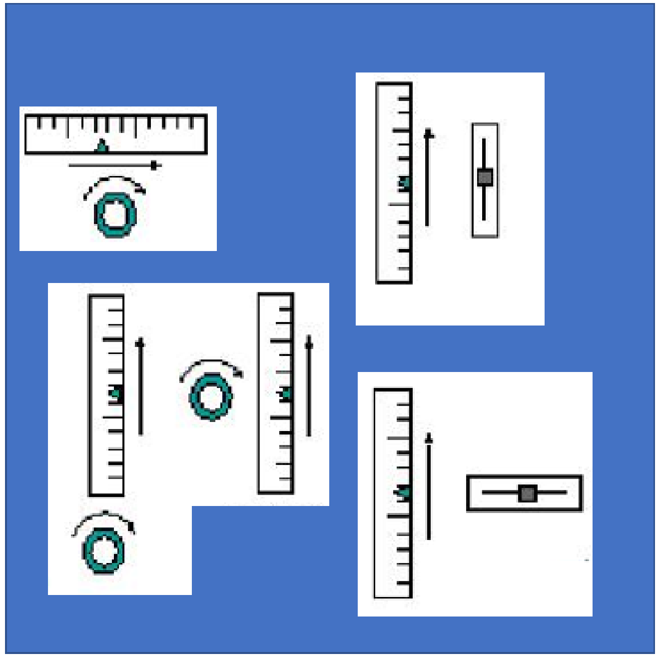
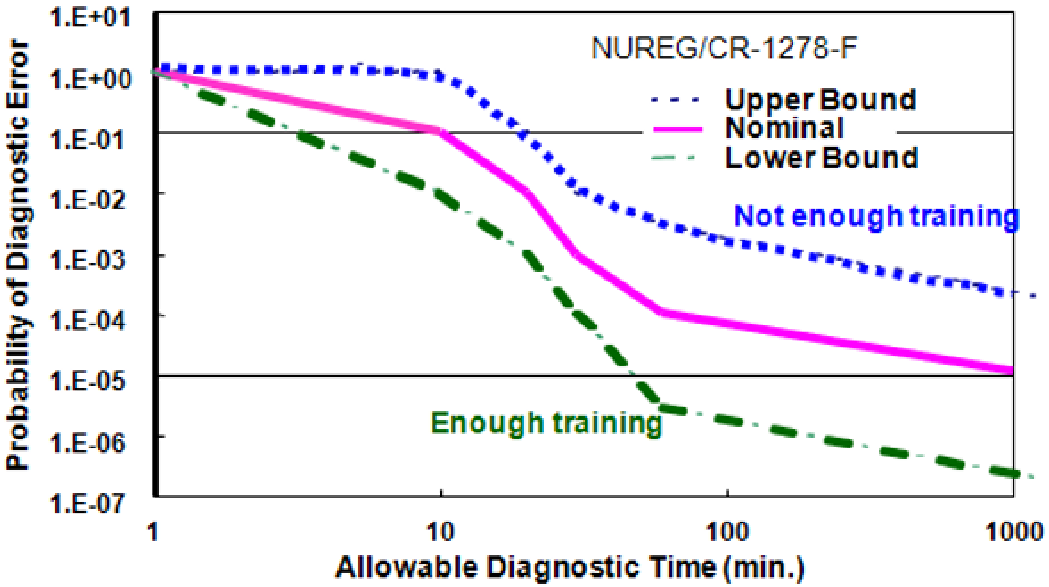
4. HUMAN ERROR AND HUMAN RELIABILITY

Human Performance Shaping Factors





- ❖Population stereotype
- ❖Local and cultural factors
- ❖Error likely situation and people
- ❖Accident prone situation and people

4. HUMAN ERROR AND HUMAN RELIABILITY

Human Performance Shaping Factors

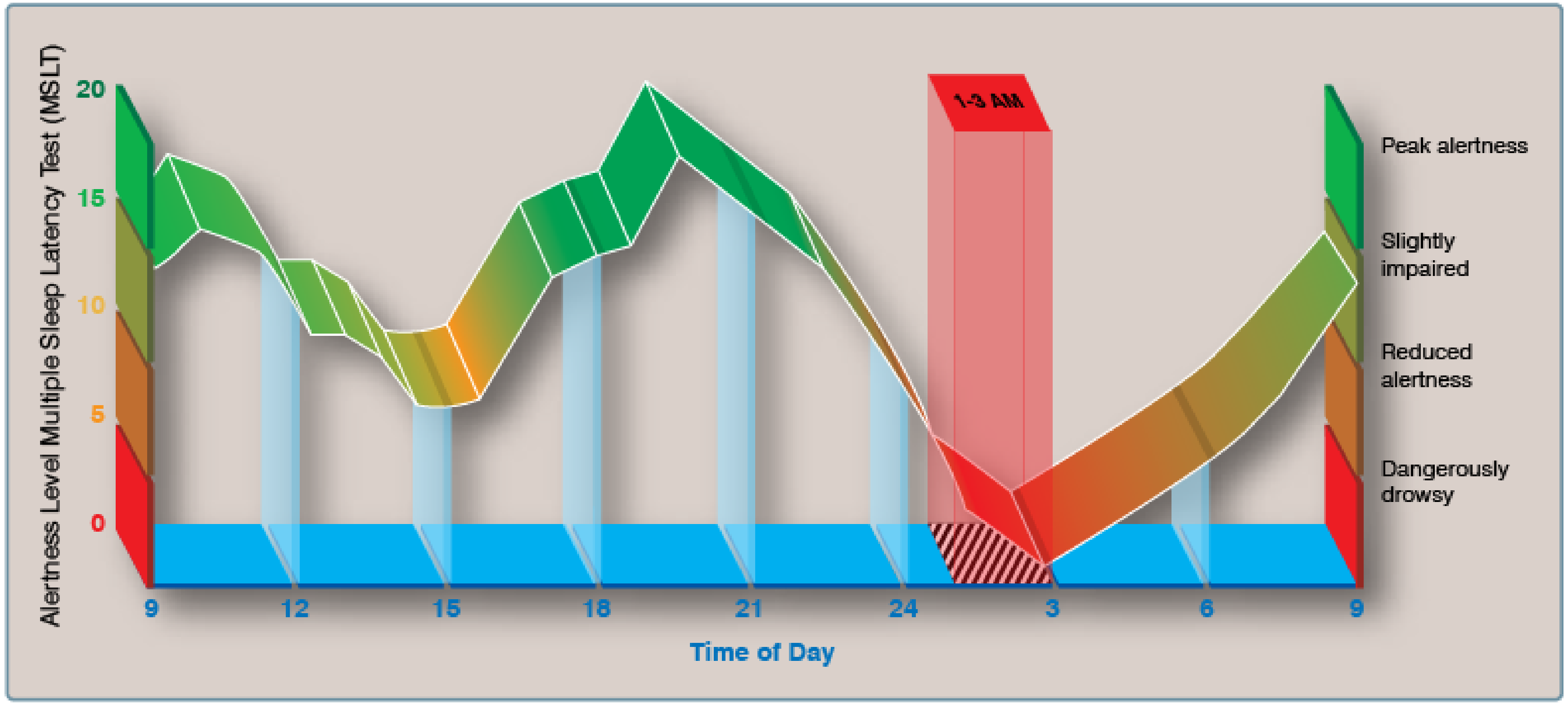


Figure 14-22. *Many human variables rise and fall daily due to one's natural circadian rhythm.*

4. HUMAN ERROR AND HUMAN RELIABILITY

Active and Latent Errors

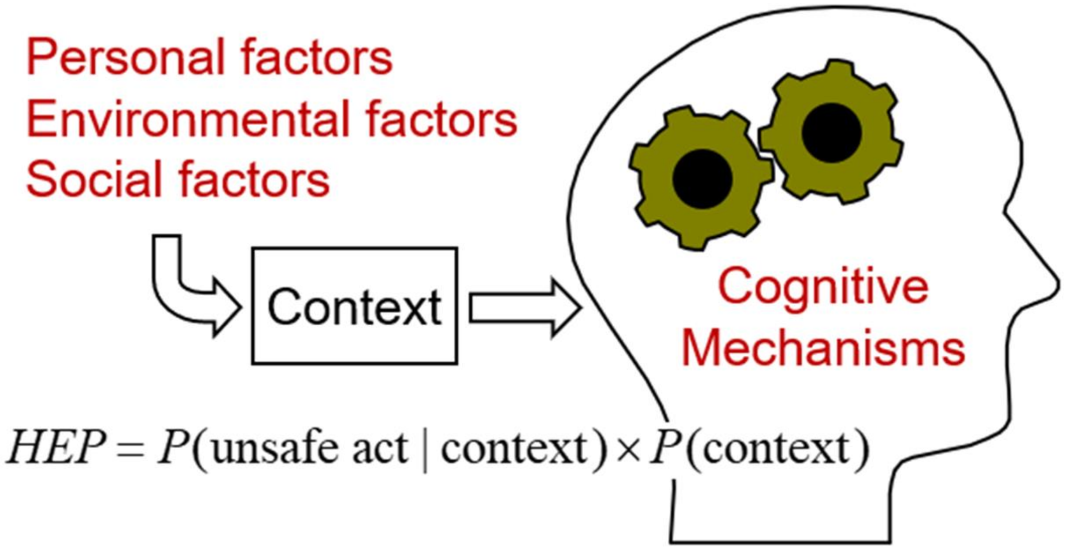
- There are two basic kinds of human errors: active errors and latent errors.*
- Active Error – An action that has an immediate effect. People are most familiar with active errors.
- Latent Error – An action that has a delayed effect. Effects are delayed in time and space and may not be felt immediately.
- Because of the time delay between error and consequence, latent errors and their causes are much more difficult to trace than are active errors.

- Heinrich's law : accidents : small troubles : near misses
  = 1 : 29 : 300

*Reason, J. (1990). *Human Error*, Cambridge, UK: Cambridge Press.

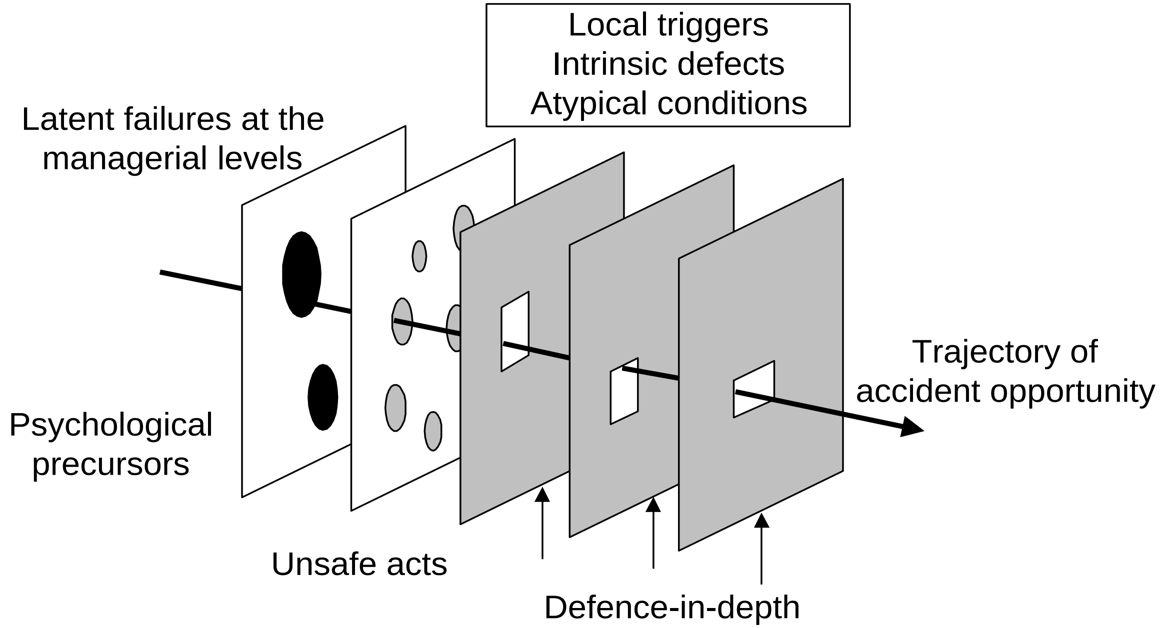
4. HUMAN ERROR AND HUMAN RELIABILITY

Active and Latent Errors



$$HEP = P(\text{unsafe act} \mid \text{context}) \times P(\text{context})$$

Ecological view of human error



Reason,J. *Human Error*. New York:Cambridge University Press(1990)

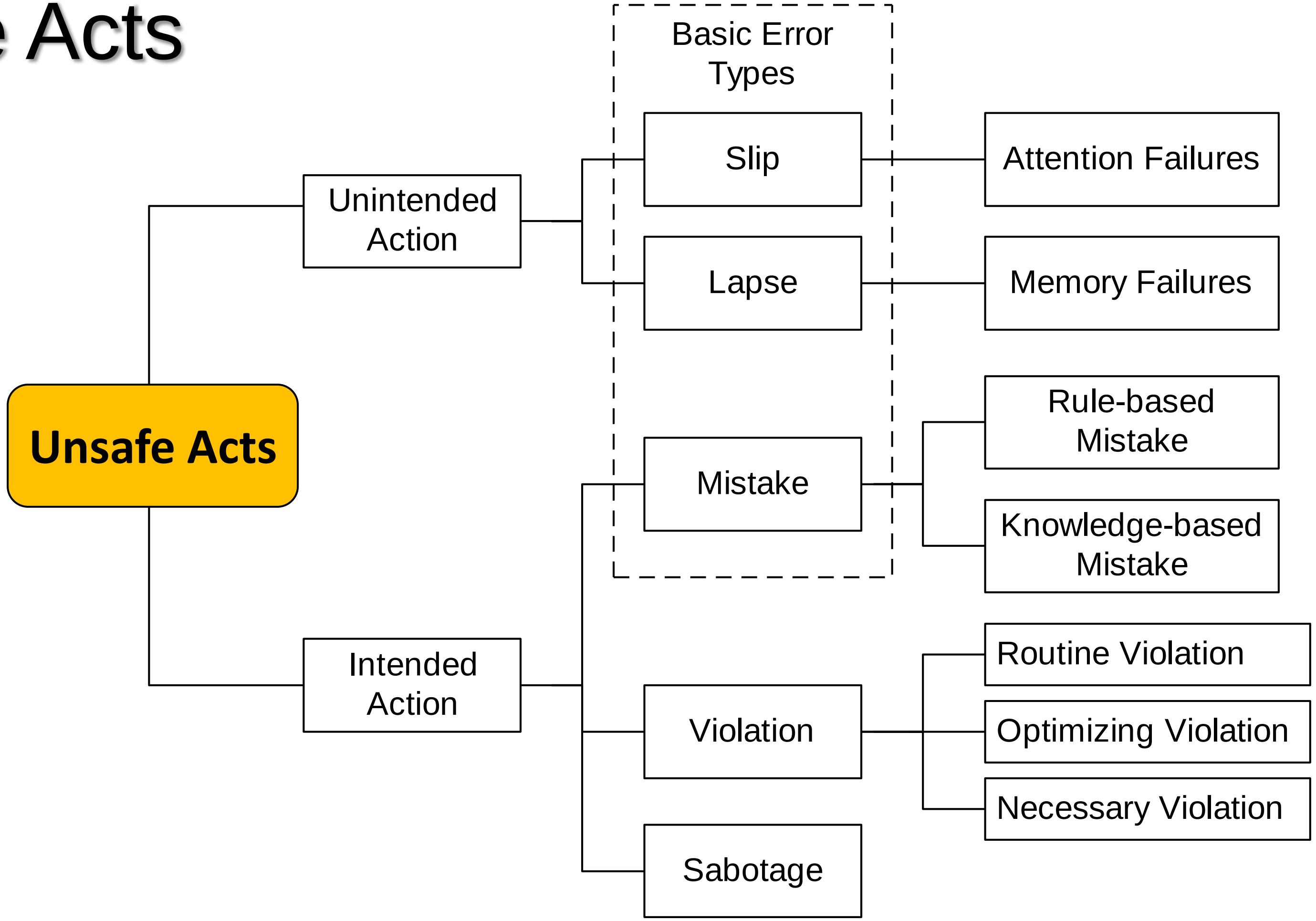
4. HUMAN ERROR AND HUMAN RELIABILITY

Reason's error taxonomy

- Slip and lapse
  - Actions deviated from intention
  - Inappropriate attention or memory failure
- Rule-based mistake
  - Intentional error at rule-base level
  - Wrong use of correct rule or wrong rule
- Knowledge-based mistake
  - Intentional error at knowledge-base level
  - Limited resources, heuristics, and biases

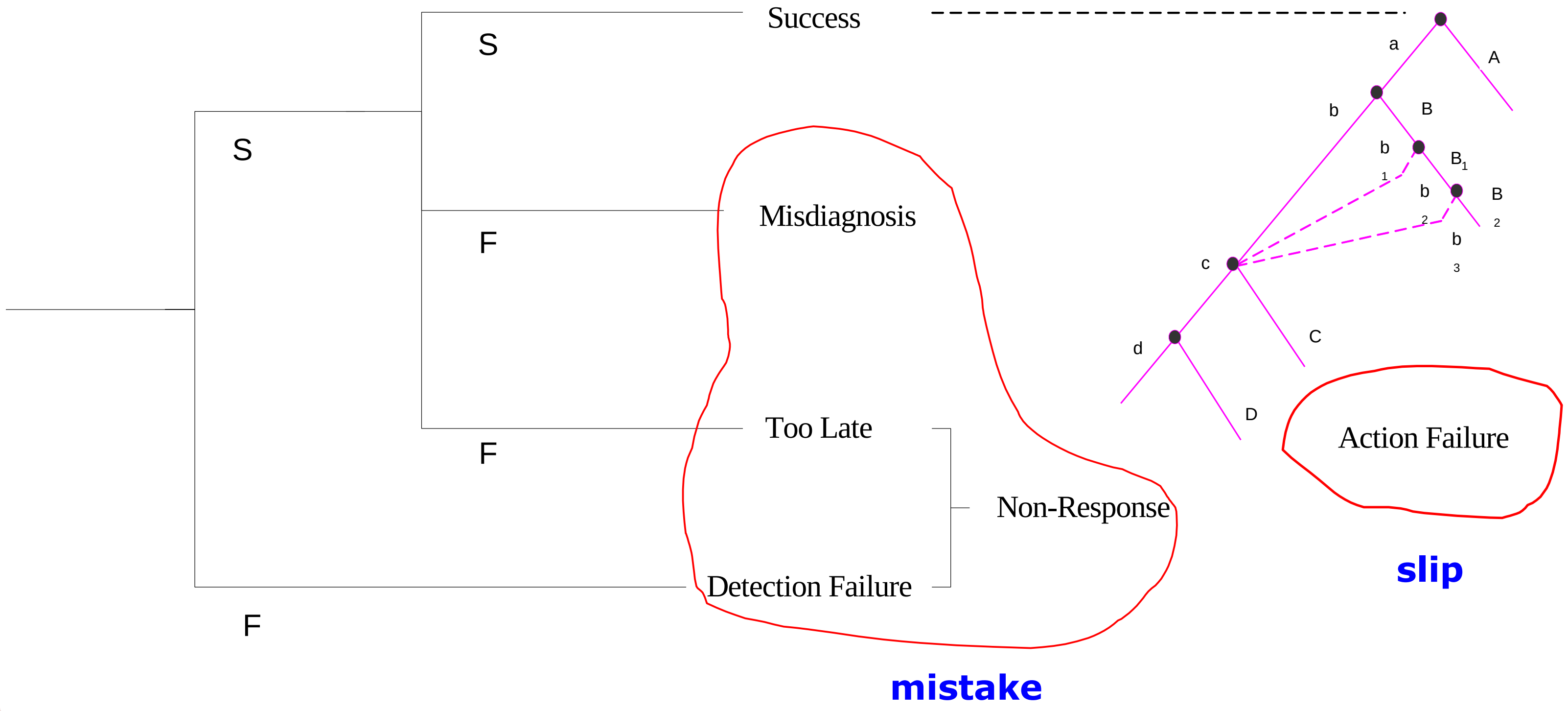
4. HUMAN ERROR AND HUMAN RELIABILITY

Unsafe Acts



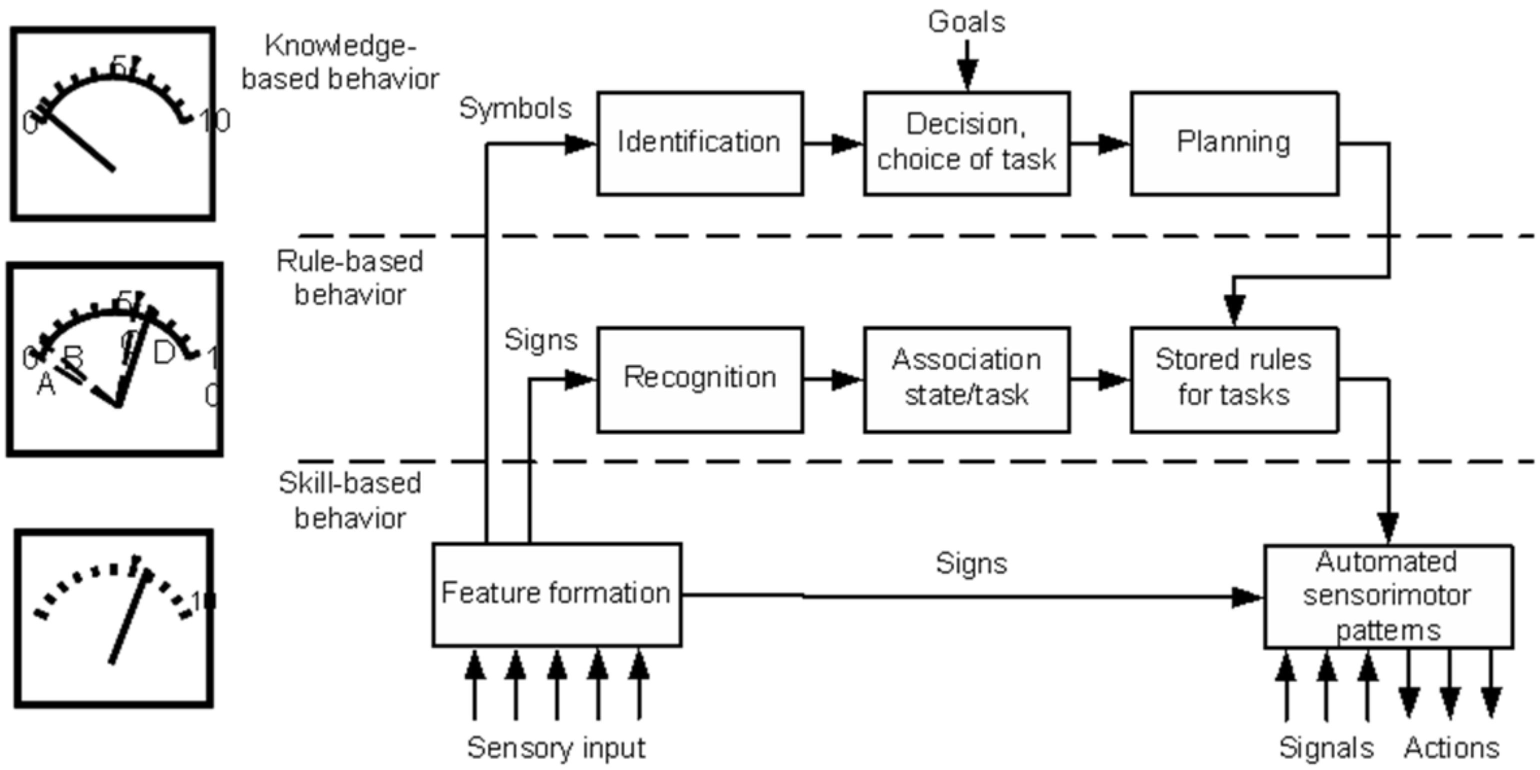
4. HUMAN ERROR AND HUMAN RELIABILITY

Event	**Detection**	**Diagnosis / Plan**	**Execution**



4. HUMAN ERROR AND HUMAN RELIABILITY

Rasmussen's SRK model



Rasmussen J., IEEE Trans. System Man and Cybernetics 13.3(1983)

4. HUMAN ERROR AND HUMAN RELIABILITY

Active and Latent Errors

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**Reason, J. (1990). Human Error, Cambridge, UK: Cambridge Press.*

4. HUMAN ERROR AND HUMAN RELIABILITY

Human Error Type in PSA

TYPE	DESCRIPTION	IMPACT ON PSA
A	Human actions before the initiating event during normal operation that degrade system availability	Mis-calibrations, misalignments explicitly modeled in the PSA (system fault trees)
B	Human actions that contribute to initiating events	Not explicitly modeled in the PSA for full power mode (except when using fault trees to model initiating events). Treated at IE data level. Explicitly considered for Low Power and Shutdown PSA
C1	Human actions during the accident following the correct procedures	Human failure event (HFE) explicitly modeled in the PSA (event trees and fault trees)
C2	Human actions during the accident that due to the inadequate recognition of the situation or the selection of the wrong strategy, make it worse	Identified errors of commission explicitly modeled in the PSA (event trees and fault trees)
C3	Human actions during the accident, trying to recover the situation; for example repairs of equipment	Recovery actions explicitly modeled in the PSA (normally treated at sequence level)

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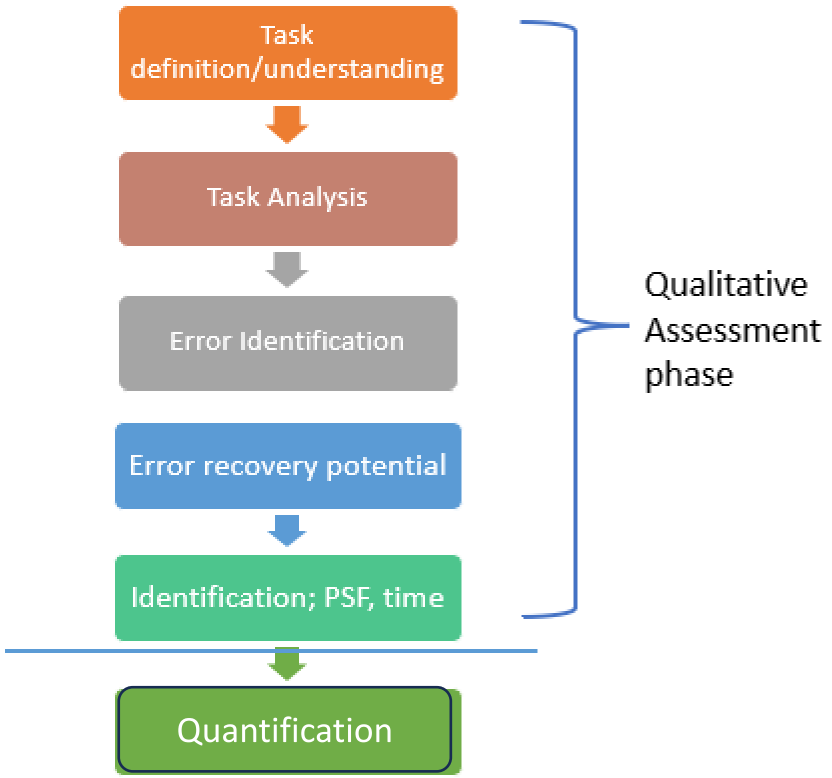
4. HUMAN ERROR AND HUMAN RELIABILITY

Human Reliability Analysis

❖**OBJECTIVES**

❖Provides a complete description of human contributions to risks or accidents and the methods to reduce those risks

❖→*Predicting the type of human error (HE) that occurs. Analize : How the error occurred, why it happened, and estimate how often it occurred.* (*possibility, probability*) →HRA methods



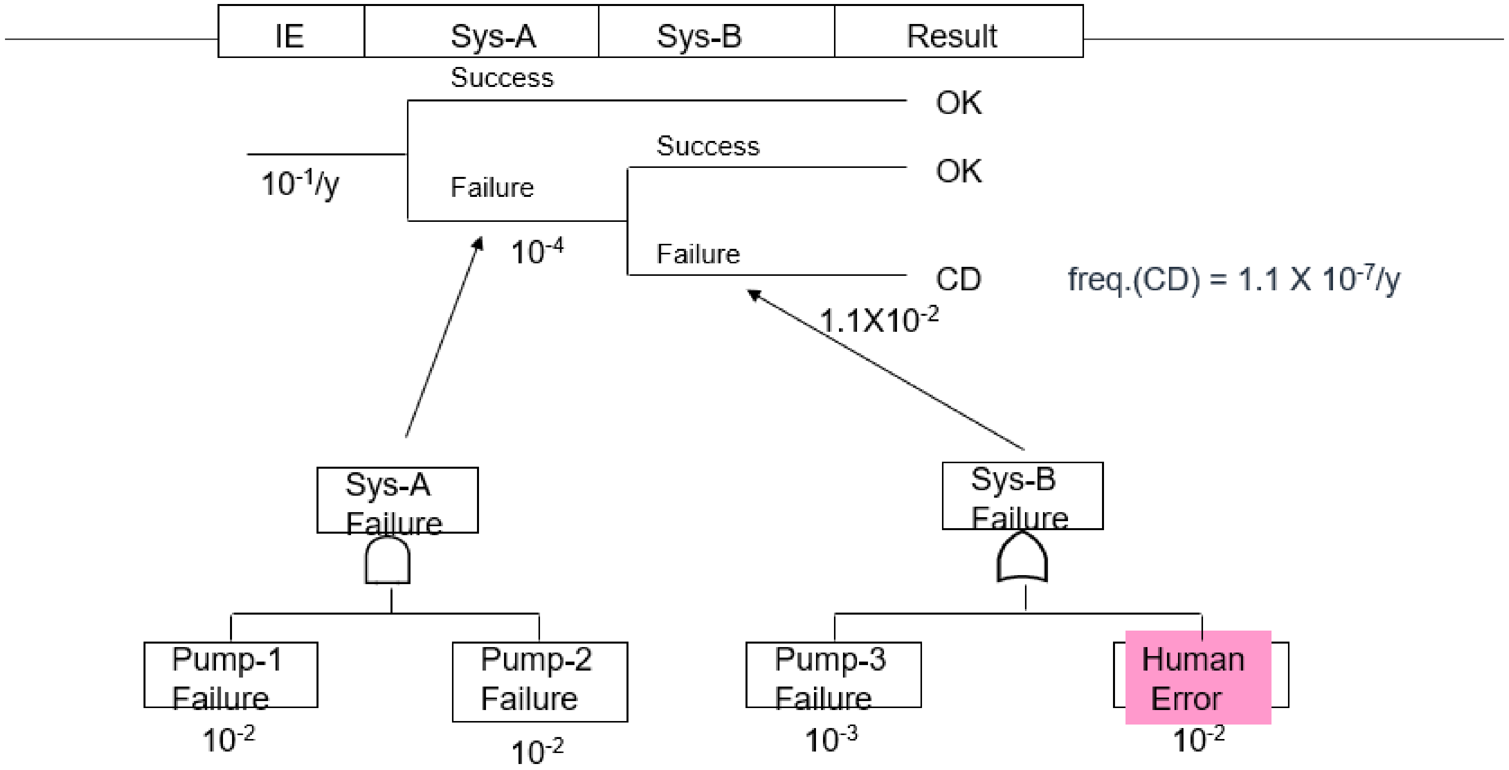
4. HUMAN ERROR AND HUMAN RELIABILITY

Integrasi HRA pada PSA (SHARP)

- Step 1 : Error identification
  Identify Potential Human Failures through Event Tree/Fault Tree
- Step 2 : Screening analysis
  Identify Potential Important Human Errors for Detailed Analysis
- Step 3 : Task analysis
  Collect Information for Error Analysis using Task Analysis
  - Define task steps based on procedure
  - Assess PSFs (Performance Shaping Factors)
- Step 4 : Modeling/integration and representation
  Select Analysis Model and Represent Human Error
- Step 5 : Quantification
  Quantification Error Probability using Available Data
- Step 6 : Documentation

4. HUMAN ERROR AND HUMAN RELIABILITY

PSA : Human Error

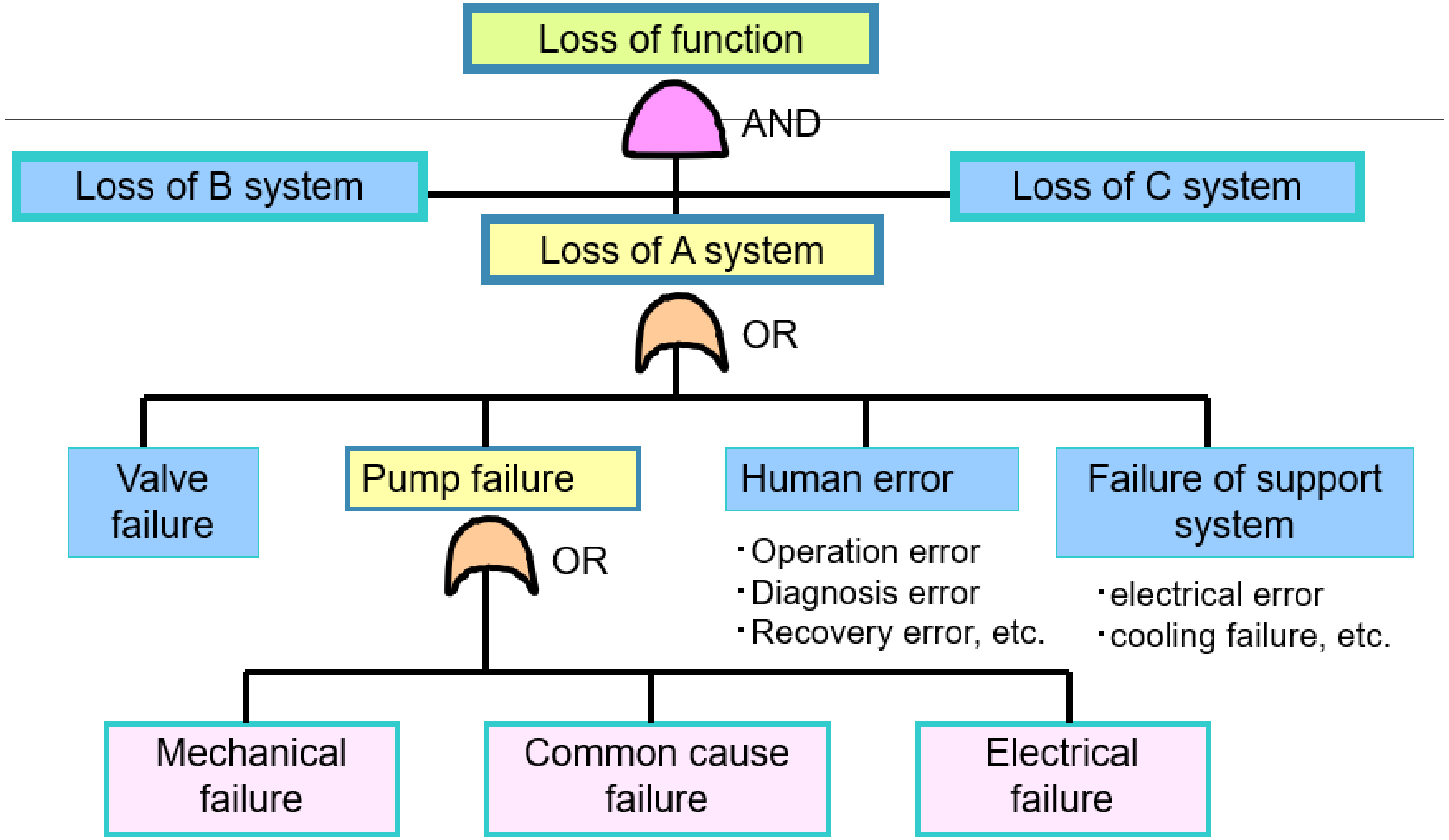


BerAKHLAK

#banggamelayanibangsa

4. HUMAN ERROR AND HUMAN RELIABILITY

PSA : Human Error



RESUME

❖Consideration of human factors is important in enhancing reactor safety, and therefore it should be applied in the design process and operation of nuclear reactors.

❖There will always be opportunities for human failure and error in the system, but value and their consequences can be suppressed to a minimum through the implementation of a good human machine system design

BRIN
BADAN RISET
DAN INOVASI NASIONAL

JAEA

Thank You!

ありがとう