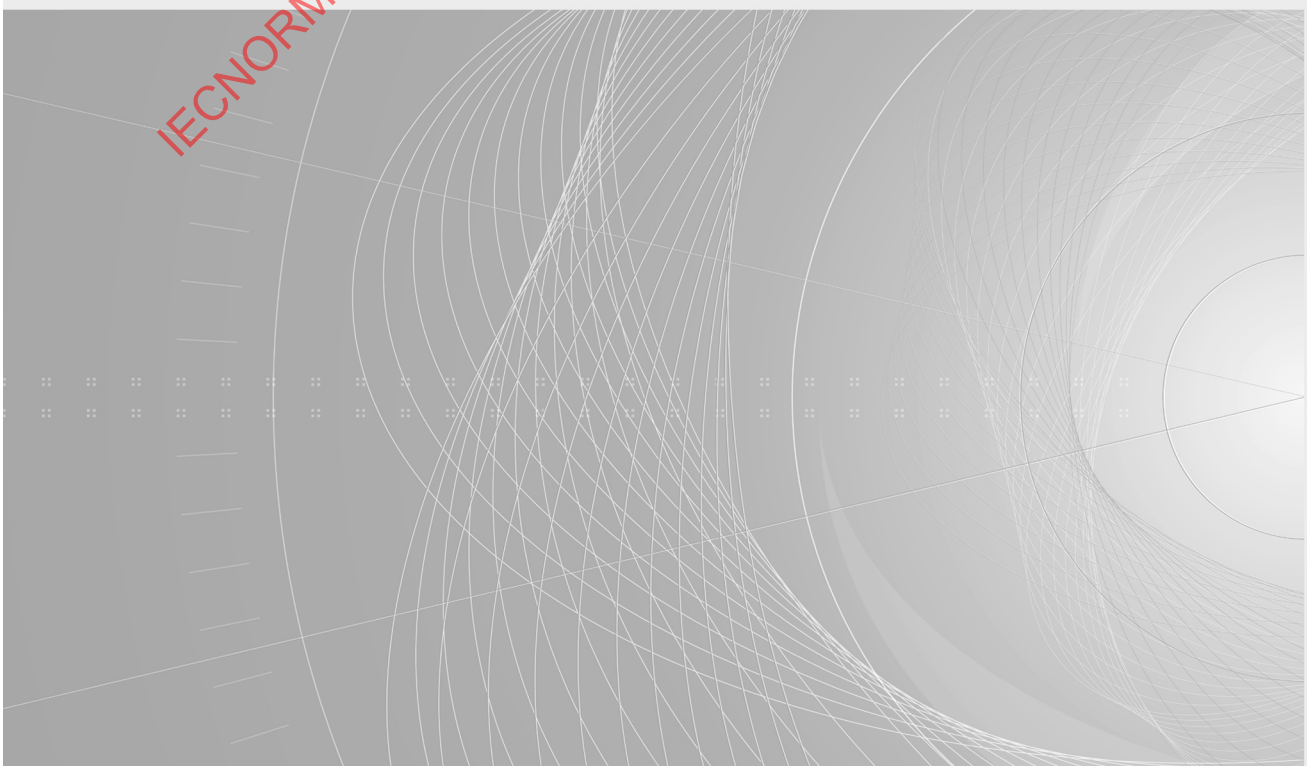
IEC TR 63214

Edition 1.0 2019-10

TECHNICAL REPORT

Nuclear power plants – Control rooms – Human factors engineering



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Nuclear power plants – Control rooms – Human factors engineering

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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NUCLEAR POWER PLANTS – CONTROL ROOMS – HUMAN FACTORS ENGINEERING

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 63214, which is a technical report, has been prepared by subcommittee 45A: Instrumentation, control and electrical power systems of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
45A/1226/DTR	45A/1247A/RVDTR

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A bilingual version of this publication may be issued at a later date.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

a) Technical background, main issues and organisation of the Technical Report

IEC 60964: *Nuclear power plants – Control rooms – Design* includes a detailed set of requirements to be applied when designing a control room and a process to implement Human Factors Engineering. The two topics are mixed and the Human Factors part is incomplete and does not reflect state-of-the-art knowledge and wording. In addition, the standard was written considering only Human Factors within the scope of electrical systems in control room design. The result is that the document does not take a holistic approach towards the design of the plant-wide control rooms and HMI, including e.g. the local control stations located throughout the plant.

The third edition of IEC 60964:2018 considers mainly the wording and the description of task analyses. The authors and the IEC Committee 45A Working Group 8 identified that changing only this aspect is already leading to a set of additional questions (e.g., concerning details of Functional Assignment and HFE V&V) triggered by outdated or incomplete information. Based on this, the Working Group realized that a minor change of the document does not solve all topics in the standard. Instead, it was proposed to publish a technical report to argue and propose a dedicated Human Factors Engineering standard, while limiting IEC 60964 to a pure control room design standard.

In addition, the IAEA is in the process of publishing a Human Factors Guide (DS492) that should also be reflected in IEC standardisation.

This document was developed to define the content of a future IEC HFE standard as a conclusion of the 2017 Shanghai IEC SC45A meeting with participants from Japan, China, Russia, Spain, France, Switzerland, and Germany.

b) Situation of the current Technical Report in the structure of the IEC SC 45A standard series

The technical report IEC TR 63214 is a fourth level IEC SC 45A document.

This report is not proving the final standard for discussion; it is recommending an international development of the standard, proving the needs and providing a first set of ideas. Outstanding work has still to be conducted.

For more details on the structure of the IEC SC 45A standard series, see item d) of this introduction.

c) Recommendations and limitations regarding the application of the Technical Report

It is important to note that a technical report is entirely informative in nature. It gathers data collected from different origins and it establishes no requirements.

d) Description of the structure of the IEC SC45A standard series and relationships with other IEC documents and other bodies documents (IAEA, ISO)

The top-level documents of the IEC SC45A standard series are IEC 61513 and IEC 63046. IEC 61513 provides general requirements for I&C systems and equipment that are used to perform functions important to safety in NPPs. IEC 63046 provides general requirements for electrical power systems of NPPs; it covers power supply systems including the supply systems of the I&C systems. IEC 61513 and IEC 63046 are to be considered in conjunction and at the same level. IEC 61513 and IEC 63046 structure the IEC SC45A standard series and shape a complete framework establishing general requirements for instrumentation, control and electrical systems for nuclear power plants.

IEC 61513 and IEC 63046 refer directly to other IEC SC45A standards for general topics related to categorization of functions and classification of systems, qualification, separation, defence against common cause failure, control room design, electromagnetic compatibility, cybersecurity, software and hardware aspects for programmable digital systems, coordination of safety and security requirements and management of ageing. The standards referenced directly at this second level should be considered together with IEC 61513 and IEC 63046 as a consistent document set.

At a third level, IEC SC45A standards not directly referenced by IEC 61513 or by IEC 63046 are standards related to specific equipment, technical methods, or specific activities. Usually these documents, which make reference to second-level documents for general topics, can be used on their own.

A fourth level extending the IEC SC45 standard series, corresponds to the Technical Reports which are not normative.

The IEC SC45A standards series consistently implements and details the safety and security principles and basic aspects provided in the relevant IAEA safety standards and in the relevant documents of the IAEA nuclear security series (NSS). In particular this includes the IAEA requirements SSR-2/1, establishing safety requirements related to the design of nuclear power plants (NPPs), the IAEA safety guide SSG-30 dealing with the safety classification of structures, systems and components in NPPs, the IAEA safety guide SSG-39 dealing with the design of instrumentation and control systems for NPPs, the IAEA safety guide SSG-34 dealing with the design of electrical power systems for NPPs and the implementing guide NSS17 for computer security at nuclear facilities. The safety and security terminology and definitions used by SC45A standards are consistent with those used by the IAEA.

IEC 61513 and IEC 63046 have adopted a presentation format similar to the basic safety publication IEC 61508 with an overall life-cycle framework and a system life-cycle framework. Regarding nuclear safety, IEC 61513 and IEC 63046 provide the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework IEC 60880, IEC 62138 and IEC 62566 correspond to IEC 61508-3 for the nuclear application sector. IEC 61513 and IEC 63046 refer to ISO as well as to IAEA GS-R part 2 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA). At level 2, regarding nuclear security, IEC 62645 is the entry document for the IEC/SC45A security standards. It builds upon the valid high level principles and main concepts of the generic security standards, in particular ISO/IEC 27001 and ISO/IEC 27002; it adapts them and completes them to fit the nuclear context and coordinates with the IEC 62443 series. At level 2, IEC 60964 is the entry document for the IEC/SC45A control rooms standards and IEC 62342 is the entry document for the ageing management standards.

NOTE 1 It is assumed that for the design of I&C systems in NPPs that implement conventional safety functions (e.g. to address worker safety, asset protection, chemical hazards, process energy hazards) international or national standards would be applied.

NOTE 2 IEC/SC45A domain was extended in 2013 to cover electrical systems. In 2014 and 2015 discussions were held in IEC/SC45A to decide how and where general requirements for the design of electrical systems were to be considered. IEC/SC45A experts recommended that an independent standard be developed at the same level as IEC 61513 to establish general requirements for electrical systems. Project IEC 63046 is now launched to cover this objective. When IEC 63046 is published, this Note 2 of the introduction of IEC/SC45A standards will be suppressed.

NUCLEAR POWER PLANTS – CONTROL ROOMS – HUMAN FACTORS ENGINEERING

1 Scope

This document provides a summary of arguments and a technical basis for the development of a new Human Factors Engineering IEC standard and the alignment of IEC 60964. Based on the provided argumentation, the participating members will vote for such an approach. The proposed content of the new standard provides the basis for fruitful discussion within IEC SC 45A WG 8 and raises interest in the development of the new standard.

The scope of the new HFE IEC standard will follow a holistic approach towards the design of the plant-wide control rooms and all HMI, including e.g. the local control stations located throughout the plant. The general principle is to consider the complete nuclear installation design as a sociotechnical system, in a holistic and integrated way.

This document is organized as follows:

- Clause 5 addresses the open points that serve as a basis for the discussion about a new Human Factors standard within IEC.
- Clause 6 proposes a basic structure for the new standard to clearly identify the scope of this development.
- Clause 7 addresses the changes needed to existing IEC standards to be aligned with a new Human Factors standard.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60964:2009, *Nuclear power plants- Control rooms - Design*

IEC 60965, *Nuclear power plants – Control rooms – Supplementary control room for reactor shutdown without access to the main control room*

IEC 61771, *Nuclear power plants – Main control room – Verification and validation of design*

IEC 61839, *Nuclear power plants – Design of control rooms – Functional analysis and assignments*

ISO 11064 (all parts), *Ergonomic design of control centres*

IAEA Guide DS492 *Human Factors Engineering in the Design of Nuclear Power Plants; Status:* DRAFT

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
function
specific purpose or objective to be accomplished, that can be specified or described without reference to the physical means of achieving it.

[SOURCE: IEC 61226: 2009, 3.7]

3.2
functional analysis
examination of the functional goals of a system with respect to available manpower, technology, and other resources, to provide the basis for determining how the function may be assigned and executed

3.3
human factors engineering
engineering in which factors that could influence human performance and that could affect safety are understood and are taken into account, especially in the design and operation of facilities

3.4
human-machine interface
interface between operating staff and I&C system and computer systems linked with the plant. The interface includes displays, controls, and the Operator Support System interface

3.5
job analysis
analysis identifying basic requirements which a job imposes on the control room staff structure, the operating procedures and training programme

3.6
local control points
local control facilities
points (or facilities) located outside the control room where local operators perform control activities

3.7
operating procedures
set of documents specifying operational tasks it is necessary to perform to achieve functional goals

3.8
operating staff
plant personnel working on shift to operate the plant. The operating staff includes the control room staff, maintenance engineers, etc.

3.9
operator interaction
interrelation between operator and the I&C system. Specifically, display of plant status by the I&C system and corresponding operator action

3.10
performance requirements
quantitative requirements specifying performance which ensure the achievement of functional goals

3.11
task analysis
identification, description and evaluation of an operator's task, in terms of its components, to specify the detailed human activities involved, and their functional and temporal relationships

3.12
tasks
actions performed by humans for the accomplishment of a functional goal

3.13
training programme
programme which is designed to train the control room staff so that they can acquire the skills and knowledge necessary for operational activities

3.14
validation
process of determining whether a product or service is adequate to perform its intended function satisfactorily.

Validation is broader in scope, and may involve a greater element of judgement, than verification

[SOURCE: IAEA Safety Glossary, 2007 edition]

3.15
verification
the process of determining whether the quality or performance of a product or service is as stated, as intended or as required

[SOURCE: IAEA Safety Glossary, 2007 edition]

4 Abbreviated terms

EPRI	Electric Power Research Institute
HED	Human Engineering Discrepancies
HFE	Human Factors Engineering
HMI	Human Machine Interface
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Standardisation Organization
I&C	Instrumentation and Control
MCR	Main Control Room
NPP	Nuclear Power Plant

NRC	Nuclear Regulatory Commission
OECD	Organisation for Economic Co-operation and Development
VDU	Visual Display Unit
V&V	Verification and Validation
WGHOF	Working Group Human Organisational Factors
WG	Working Group

5 Identified open points in IEC 60964 concerning HFE

5.1 General

This clause provides a set of open points within todays IEC documentation concerning the engineering of Human Factors (HFE). The points were addressed in the comments to IEC 60964 update 2017 and in the Shanghai IEC Meeting. The points shall provide evidence to participating countries to vote for a new development of a Human Factors standard and a harmonization in the related IEC documentation.

5.2 Limitation of scope

IEC 60964 is only applicable for Control Room Design, but includes (or is used for) two topics: Control Room Design and Human Factors Engineering.

Concerning Control Room Design, IEC 60964 reflects the state-of-the-art and provides a good set of requirements.

Concerning Human Factors Engineering (IEC 60964:2009, Clauses 7 and 9), the scope is however limited to the Control Room and the I&C equipment installed there. The de facto usage of the standard and users expectations manifested it as the IEC Human Factors standard. The limited scope creates issues of insufficiency, as some state-of-the-art methods and processes are missing.

The mix of the two topics creates confusion about the scope of Human Factors Engineering which obviously is not limited to the Control Room and the extent of covered activities (see following clauses).

In addition, the handling of Human Factors Engineering Programs in modernization projects are not covered by IEC 60964: 2009, those need to be added as the methods and important assumptions for those projects are different to new plant approaches.

Today's IEC guidance and advice on Human Factors Engineering are limited. This creates risks for suppliers' and utilities' efforts to receive approval from authorities. The latter require a state-of-the-art HFE Program.

5.3 Supplementary information

Two clauses of IEC 60964:2009 describe the Human Factors activities of Functional Analysis and Assignment (Clause 7) and Verification and Validation (Clause 9). These activities are also described – in much more detail – in other IEC standards (referenced below). This information overlap creates uncertainty and doubt.

IEC 60964:2009, 7.2 and 7.3 describe processes that are in the scope of IEC 61839.

The IEC 60964:2009, 7.4, 5.5 and Clause 9 describe processes that are in the scope of IEC 61771.

In general, a dedicated Human Factors standard focusing specifically on the engineering of HF would reduce the overlap of information and clearly assign the topic as Human Factors activities, also applicable for other control stations. Both supplementary standards include state-of-the-art information that could be brought into a broader context within a dedicated standard whose wide scope ranges from Control Room Design to all human interactions throughout the plant.

5.4 Missing information

The state-of-the-art application of Human Factors Engineering is mainly driven by NRC's NUREG 0711 titled "Human Factors Engineering Program Review Model" and different national adaptions or interpretations thereof. While IEC 60964 is used as the Human Factors standard on an IEC level, the following information is still missing and needs to be integrated. It was thus far excluded as IEC focus was set on electrotechnical equipment only. Today, the standard is used far outside this initial focus (see the IAEA references in their Human Factors Guide) and needs to be revised and extended accordingly.

- Organizational and Management of a HFE Program

  Highly important for a holistic approach, a proper implementation of HFE findings and interaction with the intended user

- Operating Experience Review

  Highly important lessons learned and the proven practice of keeping pros and avoiding cons in design

- Human Reliability Analysis

  Required by utilities and authorities and increasingly impacts multiple HFE program elements, e.g. task analysis, automation, interface design, the development of operating procedures and training, verification & validation

- Development of Operating Procedures and Training

  Strongest impact on interface design

- Design Implementation

  Measures to incorporate late changes to HMI and operating procedures

- Human Performance Monitoring

  Long-term measurement of HFE compliance and plant operation effectiveness and efficiency needed

The wording of NRC NUREG 0711 is used in the nuclear industry to communicate with authorities, suppliers and utilities. The same wording should be used in an IEC Human Factors standard.

5.5 Outdated information

IEC 60964:2009, Clause 7 titled "Functional design of the main control room" and Clause 9 titled "Verification and validation of the integrated control room system" implement a Human Factors Engineering program. The clauses include details about "Automation", "Task Analysis", "Design Verification and Validation" and "Integrated System Validation". The information provided in those clauses requires some update to present "state of the art" knowledge.

- Automation: IEC 61839 describes state-of-the-art analyses of functional requirements and allocation strategies.
- Task Analysis: The topic is described in IEC 60964 as the analysis of functional requirements and the subsequent verification of adequate allocation of identified functions to automation or manual task performance. Task analysis is the most significant HFE program element, driving the engineering of interfaces, tasks and their specification in operating procedures. It should gain back its genuine focus.

- Design Verification and Validation: The compact description in IEC 61771 is likely to be used but it lacks the description of the different design steps, the evolving design and the increasing level of Verification and Validation possibilities.
- Integrated System Validation: Neither the hardware-oriented description in IEC 60964 nor the statement of the corresponding requirement in IEC 61771 meet current needs, as authorities require a much deeper and broader (holistic) approach. This should be described accordingly.
- Staffing and Qualification: While both are mentioned as part of Task/Job Analysis, the application of the corresponding HFE program element needs to be described. Its outcome serves as input for design.

5.6 Industry needs

The mandatory reduction of human error and the witnessed level of reliability of plant personnel performance receive, as in all industries, high attention. This is based on the experiences of past incidents and the alleged influence of human error and the pressure to maintain high plant availability. In addition, an increasing level of engineering disciplines and the complexity of nuclear facilities require a special focus on system harmonization and integration to present the set of systems to a single set of humans in the control room.

Following authorities, utilities and suppliers are challenged by the need to integrate Human Factors Engineering into the design of systems and components and throughout the lifetime of nuclear facilities. Existing standards and regulatory guides are either high level and/or written from a reviewer perspective with no guidance for their application. This results in risks for all stakeholders in running nuclear projects and less than optimal implementations that do not reflect the state of the art.

Nevertheless, technical discussions in workshops (i.e. IAEA Workshops, OECD WGHOF Meetings), conference papers and - last but not least - current plant modernization and new-build projects prove that after years of development there has been already a general agreement on state of the art Human Factors Engineering.

Today supplier and utilities worldwide are in the process of defining their own processes based on different inputs e.g., IEEE, ISO, EPRI. Aligning those approaches to a Human Factors standard would be in the interest of IEC.

6 Directions for the new human factors IEC standards

6.1 General

As mentioned above, the new IAEA Human Factors Guideline and national authorities' adapted versions of the NUREG 0711 are widely used. The wording of the new IEC standard should thus be consistent with the used wording and established scope. Nevertheless, the specific topic of human system interfaces, e.g., alarm systems, control rooms, computerized displays and conventional hardwired HMIs should be mentioned but not repeated in this standard as dedicated IEC standards exist. The new standard should also be written in common industry jargon and provide guidance for the performance of the required actions.

6.2 Proposed "Table of contents" for a new Human Factors Engineering standard

The following *table of contents* should guide the development of the new document. It lists only technical clauses and pairs each entry with a collection of topics. Content is not limited to these points.

- Management of a Nuclear Human Factors Engineering Program
  - Management arrangements

    procedures and tools to be implemented, implement changes properly, integration into the overall project process, involved engineering disciplines, interdisciplinary engineering, early mockups, rapid prototypes and simulation strategy
  - Human factors team

    roles, responsibilities, implementation within the project organization, independence, required knowledge, skills and qualification, multidisciplinary staffing, implementation of operator knowledge,

    HFE as a transverse discipline
  - Overall design process

    HFE requirements management, early evaluation, iterations, configuration management
  - Identification and resolution of HFE Discrepancies (HED)

    identification, tracking, holistic approach to resolution – nature, effort and time
  - Holistic approach

    reference plant, new design vs. modernization, adapting scope, grading effort, risk significance, task complexity, existing HFE knowledge, end point vision
- Treatment of Important Human Actions

  method, qualitative data collection, design input, quantification
- Analyses providing input to design and evaluation
  - Operating Experiences Review

    method for plant-specific and external analyses, interviews, questionnaires and information retrieval, analysis, documentation
  - Functional Assignment

    Link to IEC 61839
  - Task Analysis

    hierarchical and tabular task analysis, iterative approach, detail-on-demand, connected to HFE V&V
  - Job Analysis

    method, task design, staffing, periodic training
- Development of guidance for the design of Human Machine Interfaces

  principles of operation, style guides, interaction concepts, interface behaviour
- Development of Guidance for the Design of Control Centers

  Link to IEC 60964 and IEC 60965
- Development of guidance for the design of the Human Machine Interfaces of local control stations and plant components

  implementation, maintenance, special work environment, communication
- Development of guidance for the development of Operating Procedures

  LINK to IEC;

- Development of guidance for the development of operator training
  LINK to IEC;
- Human Factors Multistage Verification and Validation
  Link to IEC 61771, multistage verification and validation
  - Static Verification and Validation
    early evaluations, user involvement, measuring
  - Dynamic Verification and Validation
    design and system test, measuring
  - Integrated System Validation
    stepwise approach, measuring
- Implementation and startup
  reference configurations, early performance measurements, late changes
- Follow up of human performance
  HFE baseline, measuring, driving permanent improvements

6.3 Graphic to guide the design

The process to implement Human Factors activities will be a key part of the standard. Figure 1 should guide the discussions during the development of the standard. The figure deviates from existing standards and authority documents. It presents an HFE program which can be effectively integrated into a project throughout its lifecycle phases, taking the following into consideration:

- The majority of the designs of human/plant interaction are derived from reference plants, taking the operating experience (e.g., observation of real operating situations) thereby gained into account. The maturity of past designs and the HFE principles and practices applied throughout these designs are both credited in the adaptation phase (see Figure 1) of current design projects. The inherited HFE program governs the Human Factors activities throughout the design.
- Project work does not progress along the classical strict waterfall scheme shown in IEC 60964 or ISO 11064. The timely combination of design and the verification and validation of its HFE aspects yields an iterative process. It is highly important that project managers and configuration managers take advantage of the increased certainty in the adequacy of the designed human interactions.
- Analyses in the beginning of the design are highly important as a base for the overall concepts of plant operation and human/plant interaction concept. Those need to be performed in the beginning as their outcome serves as input for the overall project's conceptual design phase and basic design phase and produces highly important basic knowledge about a design.
- Human Factors Verification needs to be performed during several design steps, resulting in multistage verification and validation. The information available should be used as early as possible in order to perform human-centered analyses. An initial paper-based static review is followed by reviews in a dynamic environment and finalized with the Integrated System Validation.

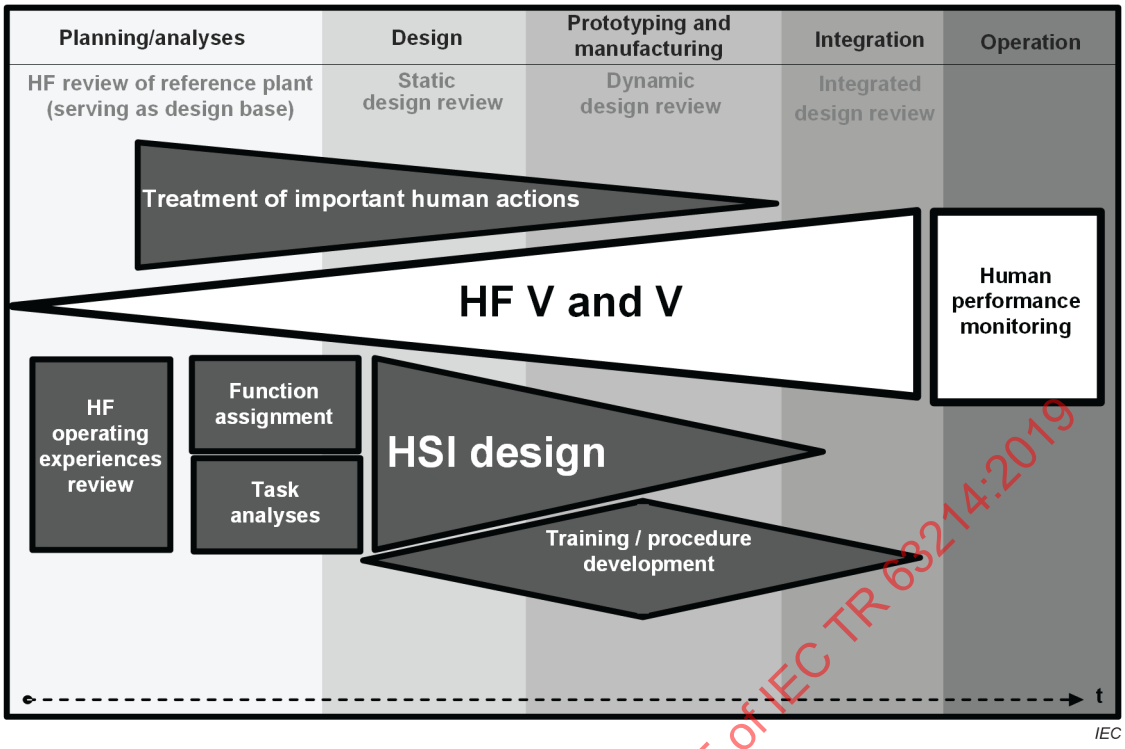

Figure 1 – Human Factors Engineering Process (to be discussed)

7 Impact on other IEC standards

7.1 General

The new IEC Human Factors standard will be on the same level as IEC 60964 and will be the second encompassing document within WG 8. Figure 2 shows the new structure. There has to be taken due account of the relationship between standards in WG 8 when updating the IEC 60964 and the new HFE standard.

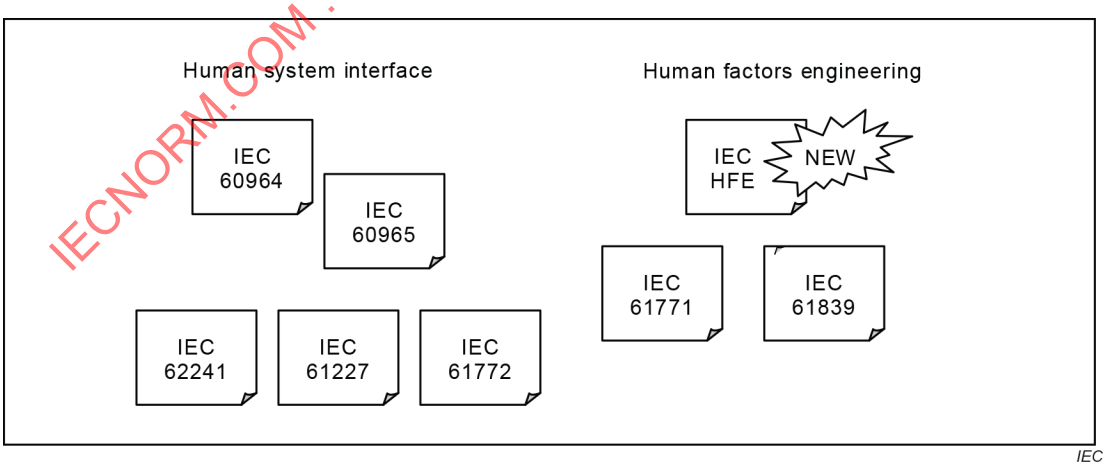

Figure 2 – New WG 8 document structure (to be discussed)

7.2 IEC 60964:2009 Control Room Design

Clause 7 titled “Functional design of the main control room” will be included in the new Human Factors Engineering standard. A reference will be made in a Human Factors clause in IEC 60964.