HUMAN FACTOR ENGINEERING APPLIED TO NUCLEAR POWER PLANT DESIGN

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INTRODUCTION

For the design and construction of new nuclear power plants as well as for maintenance and operation of the existing ones new man-machine interface designs and modifications are been produced. For these new designs Human Factor Engineering must be applied the same as for any other traditional engineering discipline.

Advantages of implementing adequate Human Factor Engineering techniques in the design of nuclear reactors have become not only a fact recognized by the majority of engineers and operators but also an explicit requirement regulated and mandatory for the new designs of the so called advanced reactors. Additionally, the big saving achieved by a nuclear power plant having an operating methodology which significantly decreases the risk of operating errors makes it necessary and almost vital its implementation.

The first step for this is preparing a plan to incorporate all the Human Factor Engineering principles and developing an integral design of the Instrumentation and Control and Man-machine interface systems.

Such a plan should state:

- Activities to be performed.

  Develop several methodologies to screen those design features that meet the general requirements and objectives of the facility and of the systems which make it up as well as for performing design evaluations from a Human Factor Stand Point.

  Implementation of those methodologies in the system design.

- Creation of a Human Factor Engineering team adequately qualified.

  The Human Factor Engineering team is an integral part of the design team and is strongly linked to the engineering organizations but simultaneously has independence to act and is free to evaluate designs and propose changes in order to enhance human behavior.

TECNATOM S.A. (Spanish company) has been a part of the Design and Human Factor Engineering Team and has collaborated in the design of an advanced Nuclear Power Plant, developing methodologies and further implementing those methodologies in the design of the plant systems through the development of the plant systems operational analysis and of the man-machine interface design.

The methodologies developed are made up of the following plans:

- Human Factor Engineering implementation in the Man-Machine Interface (MMI) design.
- Plant System Functional Requirement Analysis (SFRA).
- Allocation of Functions (AOF) to man/machine.
- Task Analysis (TA
- Human-System Interface design (HSI).
- Control Room Verification and Validation.

DEVELOPMENT

The integral plan to incorporate Human Factor Engineering principles in the design of Nuclear Plants is the first significant step to inform those persons responsible for the design, construction, development and operation of the potential benefits resulting from the Human Factor Engineering implementation (influence of Human Behavior).

THE HUMAN FACTOR ENGINEERING TEAM

The Human Factor Engineering Team must include experts in operations, instrumentation and control, procedures, training, Human Factor, computers, system engineering and nuclear technology.

The team is responsible for:

- Generate the plans and procedures pertaining to Human Factor Engineering to be followed for the design.
- Lead and review the activities related to design, development, testing and evaluation.
- Recommend and provide solutions for the design deviations found from a Human Factor stand point.
- Assure that the activities carried out adhere to the established plans and generated procedures.

The Human Factor Engineering team is an integral part of the design team and is strongly linked to the engineering organizations but simultaneously has independence to act and is free to evaluate designs and propose changes in order to enhance human behavior.

Within the organization it must be positioned in such a way that it will report directly to the project manager or engineering manager (depending on the scope of these activities) while it will make support to all the groups.

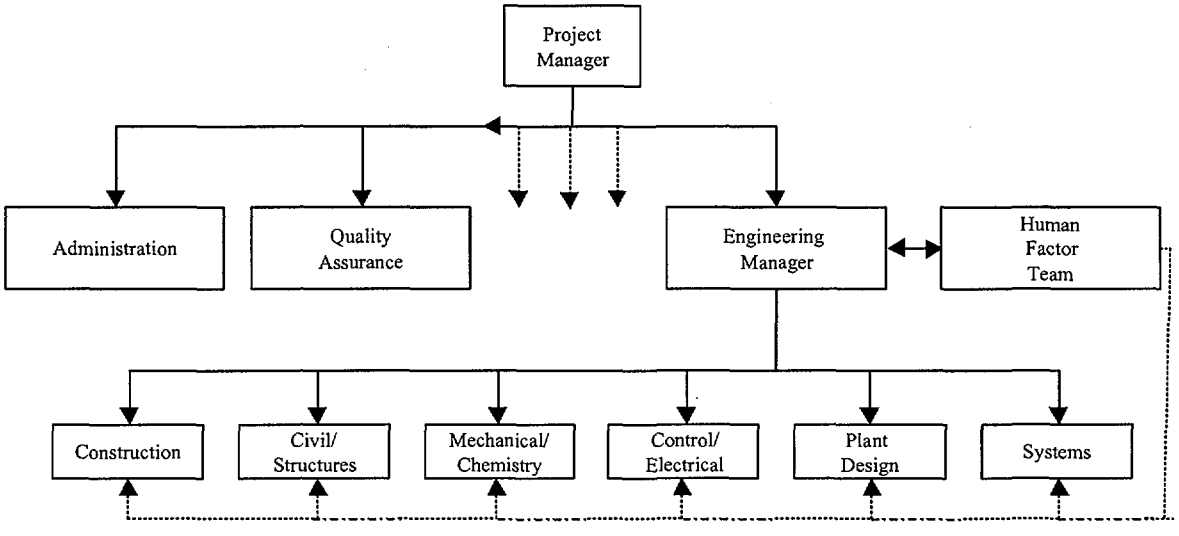

Figure 1: Human Factors team location into the design organization

IMPLEMENTATION PROCESS

According to the Integral Plan, implementation of the Human Factor Engineering concepts in the design requires some activities such as generating the corresponding plans and procedures and implementing these along with the corresponding interfaces in all the design stages.

Implementation plans were prepared taking into account former plant designs and incorporating the Human Factor criteria so that the result was an evolution and advanced design, which incorporates the Human Factor Engineering concepts and takes into account lessons learned from operating experiences. This way the new design will minimize potential error areas and will decrease potential causes for human error.

Integral design process, incorporating the Human Factor Engineering concepts and principles is summarized in Figure 2.

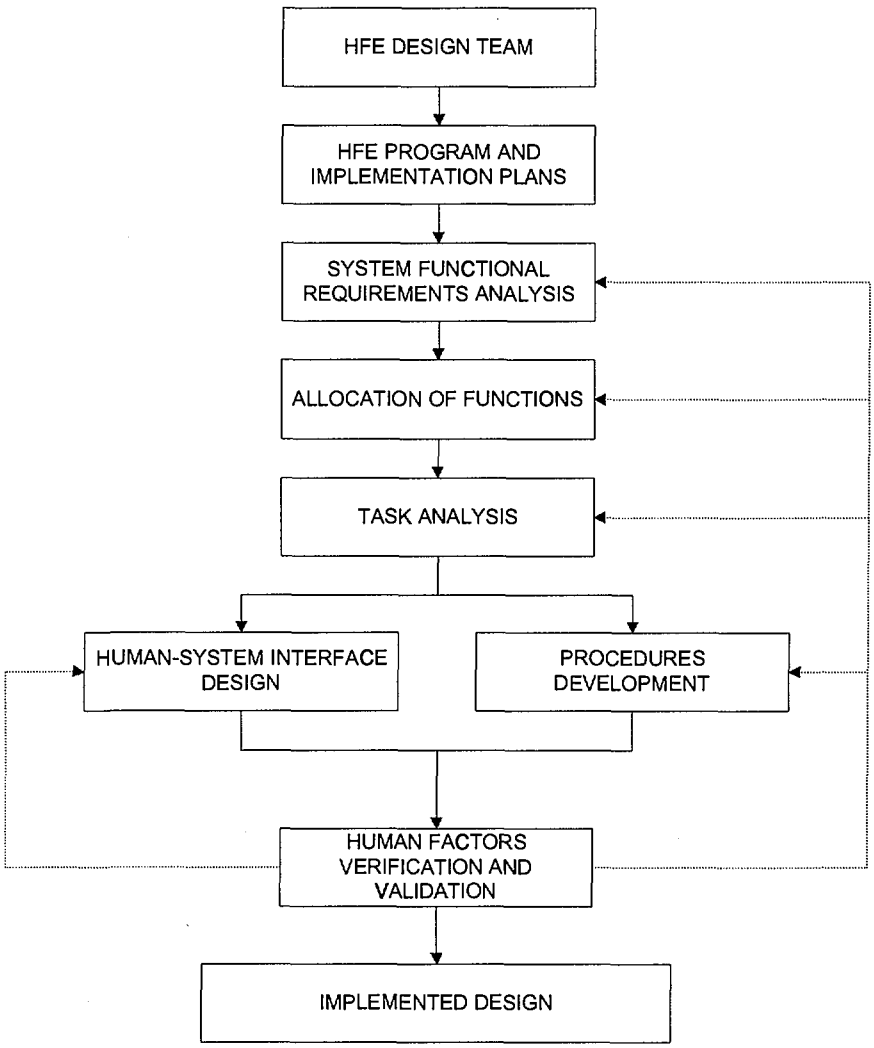

Figure 2: HSI Implementation process

PLAN IMPLEMENTATION

Implementation of the designed plans is done by the Human Factor team in close collaboration with the rest of the design teams. Constant communications and data exchange is vital for the development of the process and results in a constant feedback of data, evaluations and ideas which are used to optimize the design throughout the process.
The initial concept is using what already exists and correct it applying the appropriate Human Factor Engineering concepts but without provide their corresponding operating experiences.

The process can be divided into two big blocks:

- Operational Analysis
- Human System Interface Design

A. Operational Analysis

Operational analysis provides results that will be used for the interface design. Further evaluation of this will serve as feedback to the analysis performed in order to correct and/or modify, as appropriate. This way the whole process optimizes the design and achieves and achieves a significant decrease of potential for human error and so it results in a positive effect on plant safety and reliability.

According to the established plans, operational analysis is performed by following these three steps:

- System Functional Analysis (SFRA)
- Allocation Of Functions (AOF)
- Task Analysis (TA)

1. System Functional Requirements Analysis (SFRA)

   First step prior to the analysis of every system functions is to check or verify that all the operating experiences and lessons learned from former designs have been incorporated in the new design.

   In the second stage the implementation plan designed is performed. The Human Factor Team must answer the question: WHAT does the system do?.

   Each system functions are identified and they are classified as safety-related or non-safety related.

   The Human Factor Team identifies for each function the processes that the system performs to carry out the function and determines which parts of the system are involved in each of the processes. The different ways in which

processes can be grouped to perform a function define the different Operating Modes and the possible Operating Mode Changes that can be done.

After reviewing every function and every process, instrumentation required by the operator in order to know these have been performed is identified.

Later on, review of the system design done by Engineering results in a list of components, with their corresponding statuses, required to perform each of the processes and, subsequently, the different operating modes as well as the support requirements that allow each component to get its corresponding status.

2. Allocation Of Functions (AOF)

In order to allocate the different functions the Human Factor Team must answer the question: WHO must do it?

Using the information gathered from the above Functional Analysis as a basis, this information is then analyzed with the aim of allocating functions to the operator, to the machine, or both, taking into account human capabilities and limitations to interface with the system.

The process starts with the definition of the hypothetical allocation done by Engineering for each of the different Operating Modes associated to the functions of the system and then this hypothetical allocation is evaluated, taking into account the Human Factor criteria, by answering the following questions:

1) Man meets core performance requirements?

2) Man meets human performance requirements?

3) Cost trade off acceptable?

4) Is HF structure adequate?

5) Is cognitive support adequate?

6) Is job satisfaction optimal?

Each of these questions addresses several aspects which allow to evaluate the hypothetical allocation performed.

As a result of this evaluation, changes can be recommended in order to modify the level of automation of the design done by Engineering.

3. Task Analysis (TA)

In order to perform the Task Analysis, the Human Factor Team must answer the question: HOW to do it?, taking into account each of the tasks allocated to the operator during the Allocation of Functions stage.

Task Analysis has three stages:

- Initial Task Analysis
- Detailed Task Analysis
- HFE Analysis and results

a) In the first stage (Initial Task Analysis) all the operations that the operator has to perform are analyzed following these steps:

♦ Operating Sequence Scenarios (OSS) Definition

The appropriate Scenarios (operating sequences) are defined taking into account the different plant conditions under which each of the operations pertaining to every Operating Mode for all the system functions must be performed.

♦ Task Identification

For each scenario previously defined tasks to be performed are identified, and the sequence of tasks that make up every operating sequence is determined.

Coincident tasks associated to different sequences allows to determine the minimum number of independent tasks to be performed for a system. The so called Associated tasks are also identified.

Considering the different system components operation each of the tasks identified is subdivided into individual activities. A set of individual activities performed sequentially makes up the Individual Activities Sequence Chart for every Task.

Analysis of each task taking into account the conditions under which these must be performed for each operating sequence allows for determination of critical tasks.

Critical Task identification is very important in order to consider them in a special way when performing the Detailed Task Analysis.

The Human Factor Team will analyze more in depth the activities to be performed by the operator if these are part of a critical task, and will establish some indications to be kept in mind when preparing the corresponding procedures. It may even be decided that a critical task will require a higher degree of automation because it will have certain requirements that the operator must not face. However, should this task

not be critical, it could be performed by the operator without difficulty since the conditions under which it must be performed are quite different.

A graph called Operating Sequence Diagram (OSD) for each task allows overall observation of the different activities that make up a task.

b) In the second stage (Detailed Task Analysis) the so called Table Data Form is prepared for each of the activities of every task to be performed by the operator. In this Tale Data Form the Human Factor Team will include data corresponding to all the characteristics of a given activity such as:

- Task Identification
- Activity number
- Behavior
- Object of action
- Information requirements
- Means of action
- Frequency of action
- Connections with other tasks
- Feedback requirements
- Job performance aids
- Communications

c) In the third stage (HFE Analysis and results) the Human Factor Team analyzes the set of data included in the Table Data Form for each of the activities and obtains results such as: Instrumentation and controls required for performing each activity, messages and system feedback required, etc.

The set of requirements for each activity along with the review of the design done by Engineering allows the Human Factor Team to obtain the results corresponding to the analysis performed, which are the following:

- Operating Sequence Diagrams (OSD)
- Identification of Critical Tasks
- List of Instruments and Controls
- Location of Instruments and Controls in Main Control Room
- Discrepancies from the current design
- Procedure Recommendations
- Communications Requirements
- Job Performance Aids

B. Human System Interface (HSI) Design

The principal objectives of the HSI design are to provide controls necessary for tasks allocated to the operator and provide the operator with accurate, complete, and timely information regarding the functional status of plant equipment and systems.

The HSI design starts with the results of the operations analysis and with the design basis of the plant design. These results and design bases are translated into hardware an software design requirements which are, in turn, written into the applicable specifications and included in the hardware drawings and software programs.

According to the Human-System Interface Design Implementation Plan, specifications to determine the following items were prepared:

- Main Control Room Architecture
- Control Panels Layout
- Allocation of Safety related and non-safety related panels in the Control Room
- Type of control to be used /Hardware or Software)
- Symbols, color coding and layout, (Style Guide)
- Display Primitives (DPs)
- Operating Displays Structure

Using the above mentioned Design Specifications the Human Factor Team designed the Operating Displays for each of the systems.
For each system a report was prepared showing those displays required for the operator to be able to perform the tasks allocated to this in the AOF. These displays include the instrumentation and controls defined for each of the tasks analyzed in the corresponding Task Analysis for both safety related and non-safety related functions.

Later on, signals which must be shown in the displays and or controls included in the system screens were assigned this resulting in tables which permit associating each of the symbols shown on the screens with the addresses shown in the System Logic Diagrams. This is the link between the Control Room screens and the facility itself.

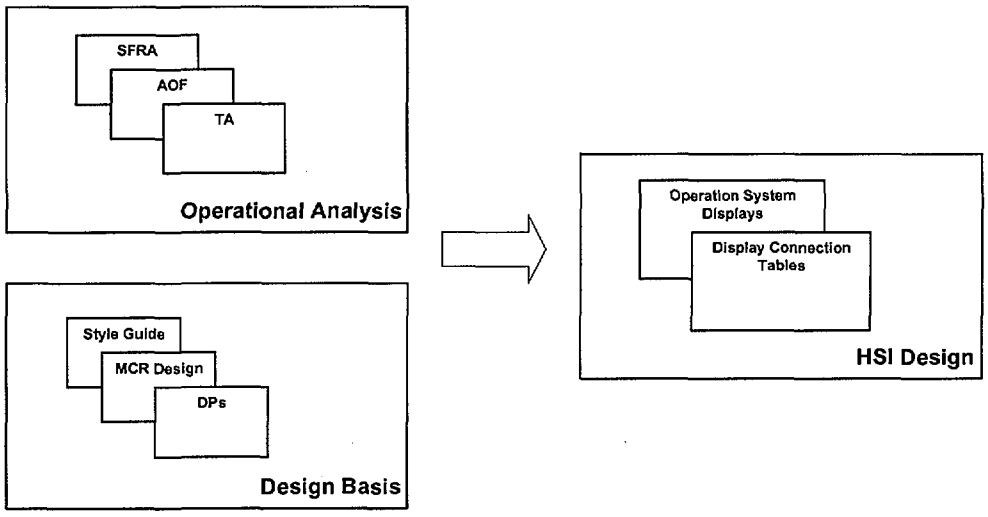

Figure 3: HSI Design Process

VERIFICATION AND VALIDATION PROCESSES

The Verification and Validation processes are performed before and after completion of control room full-scope simulator, to verify that the necessary HSI is available in a usable format that the user can performed the assigned tasks with that HSI.

Verification and Validation seek to comprehensively determine that the design conforms to HFE design principles and that design allows control room personnel to successfully perform the tasks allocated to them. The order of the Verification and Validation activities are as follows:

1) HSI Task Support Verification
2) Human Factors Engineering (HFE) Design Verification
3) Integrated System Validation
4) Human Factors Issue Resolution Verification
5) Final Plant HFE/HSI Design Verification

A. Verification

Verification confirms that the product of each step in the development of design specifications, fulfills all requirements imposed by the previous step of the design. Using identified user tasks, verification processes are used to evaluate the availability of the correct information and controls. The process also the conformance of HSI to the HFE criteria established for the HSI. Verification is a check of the individual control room components against the plant engineering criteria, human engineering criteria, and operating and functional requirements.

The verification includes:

- Instruments and displays provided in the control room represents relevant process parameters.
- Controls and displays, whether computer generated or hardware, are arranged in a consistent and orderly pattern.
- Failed instruments and displays are easily recognizable as failed.
- Workstations are arranged so that access to the control boards is not impeded.
- Adequate controls for air temperature, humidity, and ventilation are provided.
- Controls are located so that related displays can be used to provide feedback.
- Maintenance, test, and inspection activities can be performed as planned.

B. Validation

Following integration of the HSI hardware and software, validation is the test and evaluation of the HSI to determine the user's ability to perform the assigned tasks in accordance with defined acceptance criteria. Thus, the validation process measures the ability of the user to perform the allocated tasks using the HSI that has been provided the specific task(s). Due to its position in the design process, the validation process identifies deficiencies in the preparation of user procedures and training.

The control room configuration design is validated against the functional requirements established from operations analysis. This process is achieved by simulating operations with a control room mockup. Time dependent characteristics are evaluated using a full-scope simulator.

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