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CONTROL ROOM DESIGN OF A NUCLEAR REACTOR USED TO PRODUCE RADIOISOTOPE

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ABSTRACT

A control room is defined as a functional entity with an associated physical structure, where the operators carry out the centralized control, monitoring and administrative responsibilities. Inadequate integration between control room and operators reduces safety, increases the operation complexity, complicates operator training and increases the likelihood of human errors occurrence. The purpose of this paper is to present a specific approach for the design of the main control room of a nuclear reactor used to produce radioisotope. The approach is based on human factors standards and the participation of a multidisciplinary team in the conceptual and basic phases of the design. Using the information gathered from standards and from the multidisciplinary an initial sketch 3D of the main control room is being developed.

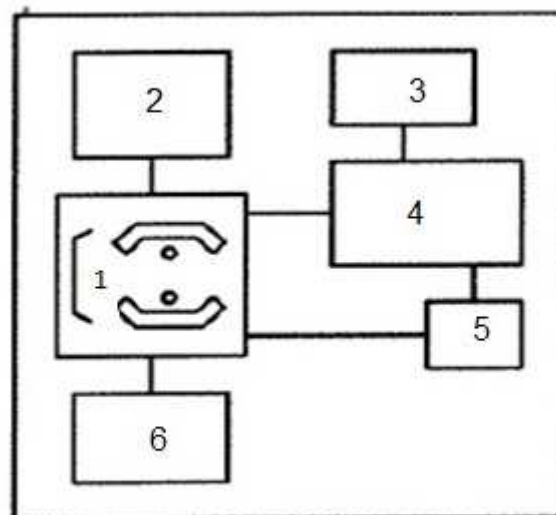
1. INTRODUCTION

Control suite is a group of functionally related rooms, co-located with the control room, and including it, which house the supporting functions to the control room, such as related offices, equipment rooms, rest areas and training rooms [1] (Fig. 1). Operator is an individual whose primary duties are related to the conduct of monitoring and control functions, usually at a control workstation, either on their own or in conjunction with other personnel, both within the control room or outside [1].

There are two major aspects of control room design that should be taken into account in an appropriate design that emphasizes safe aspects. These are the suitability of the structure of the control room to withstand possible major hazards events and the layout of control room and the arrangement of panels, controls and displays, to ensure effective ergonomic operation of the plant in normal circumstances and in an emergency. For large plants, control rooms are likely to be situated in separate buildings away from the process plant which they serve. For medium or small plants control rooms may be within the plant building. Control rooms must be designed to ensure that the risks to the occupants of the control room are within acceptable

limits and that it is suitable for the purposes of maintaining the plant control in safety condition.

Ergonomics is an inter-disciplinary research field that focuses on improving the functioning of the human–technology interaction with regard to safety. This is accomplished by taking into account the strengths and weaknesses of human performance. The goal of the ergonomics is to achieve the best possible match between the products and the users, in the context of the task to be performed. The incorporation of the ergonomics in the system design, interfaces and equipment offers a lot of opportunities for improvements with regard to system effectiveness, efficiency, reliability and safety. Human factors are a body of scientific factors about human characteristics, covering biomedical, psychological and psychosocial considerations, including principles and applications in the personnel selection areas, training, aid tools for job performance and human performance evaluation [2]. The human factors engineering (HFE) is the application of knowledge about human capabilities and limitations to plant, system and equipment design, in order to ensure that the plant, system design, human tasks and work environment are compatible with the sensory, perceptual, cognitive and physical attributes of the personnel who operate, maintain, and support it [3].



- 1 Control room
- 2 Equipment
- 3 Kitchen
- 4 Eating and rest area
- 5 Bathroom
- 6 Store

Figure 1. Control suite

The purpose of this paper is to present a specific approach for the design of the main control room of a nuclear reactor used to produce radioisotope. The approach is based on human factors standards and the participation of a multidisciplinary team in the conceptual and basic phases of the design.

2. PARTICIPATORY ERGONOMICS

Participatory ergonomics involves experts and operators actively engaged in control room development and analysis of ergonomics problems. Participatory ergonomics involves experts and end-users in planning, developing and implementing workplace changes [4]. It emphasizes control room development with a deep understanding of the activities performed by operators, of their current work practices, of their needs and skills. The goal is to encourage and support work force participation in the analysis, redesign and evaluation of their own tasks, workplaces and work practices by applying different methods and techniques [5]. Participatory ergonomics is defined as the involvement of people in the planning and control of a significant amount of their work activities, with sufficient knowledge and power to influence processes and outcomes in order to achieve desirable goals [6]. Participatory ergonomics has been successfully applied in the industrial area, including manufacturing, aviation and construction [7]. The success of this approach is directly related to the strength of multidisciplinary team involvement. It is important that the multidisciplinary team realizes the importance of participating in the process. It is important to recognize that the workers are experts at their jobs and that they can provide valuable insight into design problems.

3. METHODOLOGICAL FRAMEWORK

The principal objective of the methodological framework is to propose a methodology to develop the control room of a nuclear reactor used to produce radioisotope. It includes the use of human factors and ergonomics standards, human factors guidelines and the participation of multidisciplinary team that actively participates in control development design, bringing together different information sources, representations, perspectives and fundamental principles. The methodological framework is related to three phases (Fig. 2).

The first level concerns the definition of a multidisciplinary team. The human-centered design approach requires design activities that should take place during the system development [8]. These activities are: to understand and specify the context of use; to specify the users and organizational requirements; to produce design solutions and to evaluate designs against requirements. The human-centered design process should start at the earliest stage of the project (e.g. when the initial concept for the product or system is being formulated), and should be repeated iteratively until the system meets the requirements. Human-centered design needs a variety of skills. A range of personnel is necessary to address the human aspects of the design. This means that a multi-disciplinary team should be involved in a human-centered design process. The composition of the teams should reflect the relationship between the organization responsible for technical development and the customer. It includes human factors and ergonomics experts, human-computer interaction

specialist, user interface designer, visual designer, systems analyst, systems engineer, programmer, design engineer and end-users (operators).

The second level concerns the assignment of the responsibilities and tasks to the multidisciplinary team. The tasks and responsibilities are assigned to each team member according to their technical capabilities. The human factors expert can serve as the leader of the team and should be familiar with the methodological framework. The leader is required to coordinate the overall discussion, to manage conflicts, to keep the time schedules and to carry out the methodology. The design engineer, system engineer and programmer are responsible for hardware, software and systems development. The initial sketch of the control room and of the human-system interfaces are developed by the industrial designers, human-computer interaction specialist, user interface designer and visual designer. Operators provide information to team members in response to questions related to their work activities, needs, work practices and the operation of similar control room. During the definition of the multidisciplinary team's work process, all the necessary activities for the identification of control room mission are carried out and safety aspects, restrictions of control room and operators performance are discussed. The second level summarizes various activities, such as choice of the human factors and ergonomics standards and guidelines; choice of the reference control room and analysis of the reference control room.

The third level concerns the identification of the design requirements. It is related to the following phases:

- identify primary users;
- specify main control room layout;
- specify human-system interface design;
- specify requirements of the operation consoles;
- identify the secondary users of the control room;
- specify control room adjacency;
- specify conditions of the working environment;
- specify communication system.

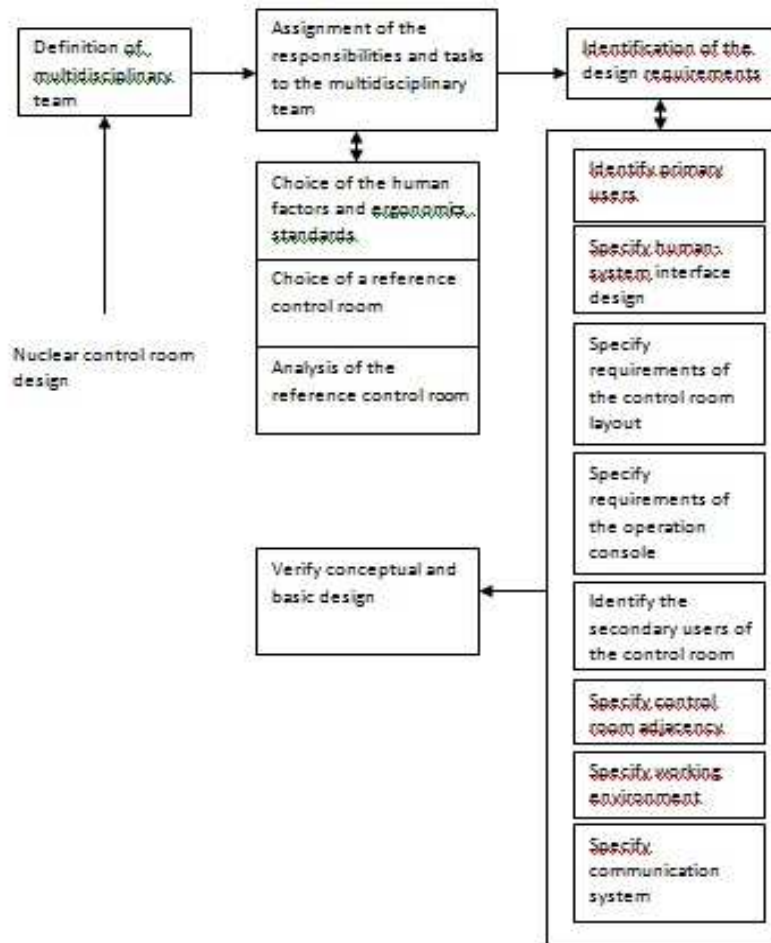


Figure 2. Methodological framework

3.1. Identify primary users

In this phase, it is necessary to define the number of operators, their staffing levels, the operator roles and responsibilities, the work organization and the constraints of the management system.

3.2. Specify main control room layout

The following layout issues should be specified:

- control room dimensions should take into account the 5th and 95th percentile users;
- design of the control room should be derived from an appropriate task analysis method, such as link analysis or hierarchical task analysis;
- emergency exits should accommodate egress by the 99th percentile users;

- adequate access should be provided throughout the control room. The layout should discourage flow from general circulation areas to ensure that necessary lines of sight are not obscured;
- operational links between control room operators, such as communications and lines of site, should be considered;
- the layout should not hinder verbal and non-verbal communication and should facilitate team working;
- the layout of the control room should reflect the allocation of responsibility and the requirements for supervision;
- circulation of all personal should be achieved with the minimum of disruption to operators;
- where supervisory positions will increase the amount of personnel circulation, it is recommended that these positions are located close to main entrances;
- distances between workstations should consider that operators are not sitting within each other's 'intimate zones';
- adequate access should be provided so that inadvertent operation of equipment during maintenance is not possible;
- behind panel equipment should be appropriately coded to reduce the potential for human error.

3.3. Specify human-system interface design

In this phase, it is necessary to define the graphics style of the human-system interfaces, the navigation strategy of the human-system interfaces, the keyboard design, the number of screens per operation console, to determine if the design will incorporate large off-workstations, safety system, communication system, hardwired panels, etc.

The design of the human-system interfaces should be based on a full task analysis and should provide the operator with the general following information:

- after initiating an action within a system the operator should be clearly informed of the result of their action;
- if there is a delay in the system that prevents the operator from being informed of the result of his/her action, the system should inform the operator of this fact;
- if an action is made in error then it should be possible to reverse such an action;
- the system should inform the operator of any deviations from safe operating levels;
- all employees on site should know what each alarm means and what the required response is and if the cause of the alarm has the potential to affect them;
- an alarm should reset automatically if the fault that generated it is rectified;
- alarm messages should be presented in a standard format, based upon existing conventions;
- alarm messages should clearly inform the operator of the reason for the alarm;
- the coding of alarms should enable the operator to recognize what the alarm indicates;
- alarms should not prevent effective communication within the control room;
- an alarm log should be provided to for diagnostic purposes;
- the design of the alarm system should prevent masking (similar sounding alarm preventing the operator from detecting the signal) and flooding of alarms ('knock on' effect on other related systems, the result of which is the triggering of other alarms).

3.4. Specify requirements of the operation console

In the design of a console it is necessary to determine if the workstation will be used as an isolated unit or in conjunction with overview displays or other workstations. Physical layouts should consider non-electronic equipment needs such as log-books and maps. In the layout of workstation should be allowed the positioning of telephones, keyboards and writing areas. This will enable operators to change posture during their shift and minimize the effects of fatigue.

The use of human factors and ergonomics standards will assist in the definition of the physical, anatomical, anthropometric, physiological and biomechanical capabilities of the operators. The specification of the layout is based on communication and collaboration requirements, the study of the process interactions, the definition of the workstation grouping, the optimum space definition and the location of visual displays for best line of sight.

Coding techniques for the console should follow international conventions. Arbitrary coding can actually propagate human error if not carried out correctly. Coding should be consistent across plant and should be used appropriately. The design of the text used in the information displays should always be capable of being easily understood by the operator; active rather than passive language should be used; sans serif fonts should be used as these have been found to be the most legible (example of a sans serif font is Arial). Labels should be used consistently across plant; labels should be used appropriately; the relationship between labels and the equipment they refer to should be clear; labels should be easily read; standard abbreviations should be used where abbreviations are required.

Display devices should be appropriate for the type of information they are presenting. Displays should be grouped logically to improve signal detection. It is recommended that formal task analysis methods be performed to determine the optimum arrangement for displays and their associated controls. The relationship between a control and its associated display should be obvious. The operator should be able to easily understand display feedback.

Controls should be appropriate for their use. They should conform to the user's stereotype, not obscure labels or displays and layout of controls should be compatible with anthropometric guidelines.

3.5. Identify the secondary users of the control room

In this phase, it is necessary to identify the secondary users of the control building, such as maintenance engineers, system engineers and others who support activities such as maintenance and radioisotope production.

3.6. Specify control room adjacency

Architects and industrial designers work with operators to determine parameters, such as space required and its intended use (kitchen, eating and rest area, bathroom); traffic flow, windows; ceilings and walls.

3.7. Specify conditions of the working environment

In this phase, architects needs to be involved to give information about heating, ventilation, circulation, noise, air quality, humidity and lighting details.

3.8. Specify communication system

The communication system should provide voice communication during normal operations, plant outages, and emergency operations. The system will include broadcast of alarm signals in plant-wide emergency situations. The wireless telephone system can be used to enable plant personnel to remain in direct communication via wireless, hand-carried telephones throughout the plant. A paging system can be used as a backup to the wireless telephone system. During failure of the wireless system, personnel communicate via a plant-wide broadcast can be available.

4. RESULTS

In this item, it is presented some results related to the application of the methodological framework. The results are partial and the mean objective was to initiate the application of the methodology. The definition of the multidisciplinary team was based on the some constraints, such as available technical capabilities. The multidisciplinary team included two human factors experts, one student of industrial design, two electronic technicians with experience on operation of simulator of nuclear power plant, four electronic engineers and two software engineers. The tasks and responsibilities were assigned to each team member according to their technical capabilities.

The multidisciplinary team decided to use the standards ISO 11064, ISO 13407 and the guideline NUREG 700 as references. The standard ISO 13407 (1999) provides guidance on the incorporation of user needs in the design lifecycle. It is characterized by the clear understanding of the context of equipment use; by the specification of the user and of organizational requirements; by the definition of task requirements and by an appropriate allocation of functions between users and technology. The NUREG 700 provides one section dedicated to basic human system interface elements, one dedicated to human-system interface systems and another one dedicated to workstation and workplace design. The basic human system interfaces elements are: information display, user-interface interaction and controls. The human system interface systems are: alarm system, safety function and parameter

monitoring system, group-view display system, soft control system, computer-based procedure system, computer operator support system and communication system. The workstation and workplace design elements are: workstation configuration, control and display device layout, labeling and demarcations, panel layout, control room configuration and control room environment. ISO 110624 (part 1) emphasizes the human-centered design approach, the combination of humans and machines, in its organizational and environmental context. Part two contains a control suite arrangement design procedure including requirements for verification/validation process and some general design principles. There is also a set of requirements for the control suite including communication, traffic and routing, entrances and exits, environmental conditions, cleaning, maintenance, etc. Part three contains a control room layout procedure, requirements and recommendations for control room layout and recommended control room dimensions. Part four contains a workstation design procedure and physical requirements and recommendations for workstation design and layout. Part five contains a checklist to verify implementation of design principles, a process description for display and control specification and high level alarm requirements and recommendations. Part six contains a control room environmental design process description and a comprehensive list of requirements and recommendations for environmental factors e.g. acoustics, lighting, air etc. Part seven contains a description of the role of verification/validation and how it can be integrated in the design process.

The multidisciplinary team decided to choose a reference control room to be analyzed. This analysis was used to discover salient features of the reference control room that should be similar to those under development. Information about the operation, control room layout, working environment, systems and equipment were obtained.

The student of industrial design is responsible for the initial sketch of the main control room, workstations layout and details about the information to be presented in the workstations and furniture layout design. Fig. 3 shows the result of the initial study. It isn't the definitive workstation layout. Studies are being developed and two better options to the workstation layout and to the furniture of the main control room were designed.

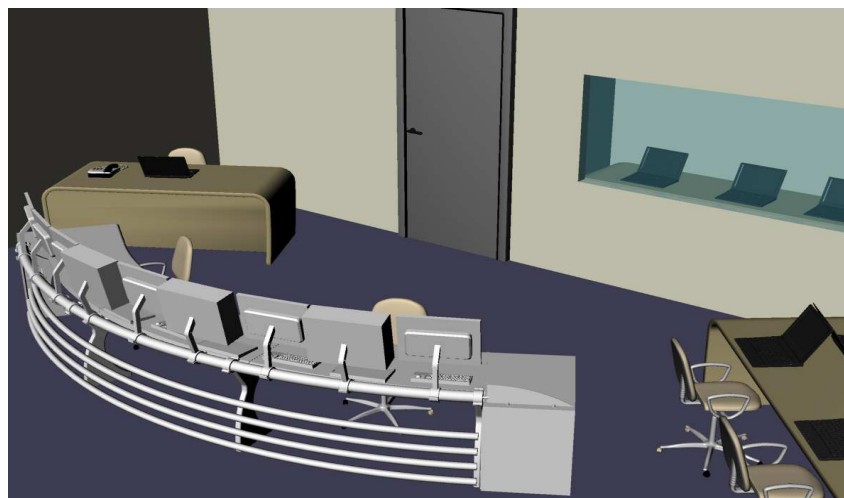


Figure 3. Example of the initial study of workstation layout

5. CONCLUSIONS

The purpose of this paper is to present an specific approach for the design of the main control room of a nuclear reactor used to produce radioisotope. The methodology includes definition of a multidisciplinary team, assignment of the responsibilities and tasks to the multidisciplinary team and identification of the design requirements. The standards ISO 11064, ISO 13407 and the guideline NUREG 700 were used in the definition of the design requirements. A digital control room of a research nuclear reactor was defined as reference control room. This digital control room was analyzed. In the phase of the identification of the design requirements the primary users were identified, the requirements of the human-system interface, of the control room layout, of the operation console, of the control room adjacency, of the working environment and of the communication system were specified. The analysis of reference control room was done using data sources from the final safety analysis report, systems design documentation and information received during visits in the reactor site. The design solutions were made considering the appropriate use of the control room, emphasizing that work practices in complex industrial should be based on the notion that the human is the most important link in complex socio-technical systems. What we really need are control rooms that support actions of the operators. To do so, control rooms must be designed considering that the users need to be taken account in all the phases of the design process.

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