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EMERGENCY 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. Emergency control room acts as an alternative control room for the purpose of shutting down or maintaining the facility in a safe shutdown state when the main control room is uninhabitable. The mission of emergency control room is to provide the resources to bring the plant to a safe shutdown condition after an evacuation of the main control room. An evacuation of the main control room is assumed when there is no possibility to accomplish tasks involved in the shutdown except reactor trip. The purpose of this paper is to present a specific approach for the design of the emergency 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 development phase of the design. Using the information gathered from standards and from the multidisciplinary team a 3D Sketch and a 3D printing of the emergency control room were created.

1. INTRODUCTION

Control centre is a combination of control rooms, control suits and local control stations which are functionally related and all on the same site. Control room is a core functional entity and its associated physical structure, where control room operators are stationed to carry out centralized control, monitoring and administrative tasks [1]. Emergency control room is an alternative control room for the purpose of shutting down or maintaining the nuclear plant in a safe shutdown state when the main control room is uninhabitable. The mission of emergency control room is to provide the resources to bring the plant to a safe shutdown condition after an evacuation of the main control room. An evacuation of the main control room is assumed when there is no possibility to accomplish tasks involved in the shutdown except reactor trip.

The control room design can be specified by statements of design goals, principles and requirements. Design goals are statements of key objectives that the design must satisfy to meet overall plant needs. Principles describe features that control room should embody in support of design goals. Requirements are specific statements of objectives. The principles for the design of control room include several factors such as operational requirements, operational issues associated with supervisory control, understanding of human error in operational situations, functions that operator and system use to achieve operational objectives and task analysis. Control rooms are designed and operated with the understanding that human operators are responsible for plant safety. In this role, operators plan, organize, direct plant operations, and configure automated systems to achieve operational objectives [2]

ISO 11064 [1] emphasize that ergonomic design of control centers consists of the following parts: principles for the design of control centers; principles for the arrangement of control suites; control room layout; layout and dimensions of workstations; design of displays and controls; environmental requirements for control rooms and principles for the evaluation of control centers. According to ISO 11064 [1], important questions must be addressed before the control room design is started. The framework to be used should be based on a participatory process that uses an iterative design approach. The principle steps are:

- Identify primary users: It is necessary to define the number of operators, define the roles and responsibilities, staffing levels and the number of console operators.
- Identify human-system interface design: In this phase, it is necessary to specify a graphical navigation strategy, keyboard design, the number of screens per console and develop a graphics style guide. The last decision is to determine the use of large-off-workstations, safety systems, communication system, hardwired panels, etc.
- Specify console requirements: It is one of the main system that requires ergonomics design considerations. It encompasses physical, anatomical, anthropometrical, physiological, behavioral and biomechanical capabilities in order to provide good workplace layout, working postures, material handling, line of sight and repetitive movement.
- Specify console layout: The layout of consoles need to be specified based on communication and collaboration requirements. Important factors such as ergonomic standards, work environment; stress, fatigue and task performance must be considered in console design.
- Specify secondary requirements: It is necessary to identify secondary users of the control room building, such as engineers and supervisors, who support activities in the control room.
- Specify room adjacency and space: It is necessary to determine space required, its intended use and adjacency requirements. In this phase, ergonomic requirements of the building are determined. Lighting, noise, traffic flow, ventilation, walls and ceilings should be specified.

The study of ergonomics is one of the keys to understand human behavior and human performance in interaction with complex systems such as nuclear power plant. Another field of interest is to achieve the best match between the system and its users in the context of task to be performed. Human performance may be considered from two points of view in design. Traditionally human behavior has been perceived from the perspective of causing risk to the safe functioning of the system. The other perspective emphasizes the positive contribution of human performance for productivity [3].

Human–centered design approach requires study of the combination of humans and machines in its organizational and environmental context. That is achieved by maximizing the strengths and capabilities of both humans and machines in a complementary fashion. For harmonic integration of the human component, knowledge about how operators feel and interact with each other, as well as with the control room's equipment and environment, should be taken into account [4]. The human-centered design requires activities that should take place during the system development. The 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 [5]. 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 [6].

The purpose of this paper is to present a specific approach for the design of the emergency 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 development phase of the design. Using the information gathered from standards and from the multidisciplinary team a 3D Sketch and a 3D printing of the emergency control room were created.

2. PARTICIPATORY ERGONOMICS

Participatory ergonomics is an approach that involves experts and workers actively engaged in system development and in the analysis of ergonomics problems. Participatory ergonomics involves end-users in planning, developing and implementing workplace changes. It emphasizes equipment development with a deep understanding of the activities performed by users, of their current work practices, of their needs and skills [7]. An important concept is that the ease-of-use of the equipment can only be ensured if users are actively involved in all phases of the design lifecycle. The goal is to encourage and support work force participation in the analysis, redesign and evaluation of their own tasks, applying different methods and techniques [8]. Participatory ergonomics is 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. The success of this participatory approach is directly related to the strength of group involvement. It is important that the group realize the importance of participating in this process. It is important to recognize that the workers are experts at their jobs and that they can provide valuable insight into design problems [9].

2.1. Human Factors Engineering

The objectives of human factors engineering are to ensure that the human factors requirements have been satisfactorily integrated into design, development and evaluation of the control room; ensure the necessary means for operators to perform their tasks safely; ensure that the tasks to be performed by operators are correctly specified; ensure that procedures and training requirements are consistent with desired performance; ensure that control room design is consistent with the cognitive characteristics of operators, enabling a compatible human performance with the desired mission; minimize human error; make available adequate information about the status of systems, enabling the execution of tasks by operators during normal and emergency situations. The item related to control room design defines physical arrangement of the control room, layout of the control desk, basic requirements of the humane-system interfaces, definition of systems to be monitored in the control desk and basic requirements of environmental conditions. The verification and validation process guarantee that all necessary controls, alarms and human-system interfaces have been included in the control room design, so that operators can performance efficiently the tasks in all modes of operation [10].

Increasing research efforts have yielded knowledge concerning the design of workstations, workplace, control rooms, human-system interfaces, user-interface interaction and organizational design to prevent worker discomfort, illness and also to improve productivity, product quality, ease of use and safety. Workstations shall be designed to accommodate from the 5th to 95th percentile of the intended user population. It is necessary to consider all features related to the intended users, such as gender, age, ethnic background and disabilities. Adjustability should be considered for those workstations which do not accommodate the 5th and 95th percentile users. 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 needs such as log-books, maps, telephones, keyboards and writing areas. The environmental factors such as lighting, humidity, temperature, vibration and noise should be addressed since poor environments can seriously affect operator performance.

3. METHODOLOGICAL FRAMEWORK

The methodology includes the following items: profile of the multidisciplinary team, definition of a work process for the team, assignment of tasks and choice of ergonomics methods and tools.

3.1. Profile of the Multidisciplinary Team

The multidisciplinary team included one human factors expert, one design engineer, one mechanical technician and three industrial designers.

3.2. Definition of the work process of the multidisciplinary team

This phase consisted of the description of the work process, presentation of roles, commitment dates and the activity timeline. In meetings, the team defined outlined the design goals.

3.3. Assignment of tasks to members of the multidisciplinary team

The tasks and responsibilities were assigned to each team member according to their technical capabilities. The human factors expert was required to coordinate the overall discussion, manage conflicts and carry out the methodology implementation. The design engineer and human factors expert were responsible by use and application of ergonomics standards. The sketches of emergency control room were developed by the industrial designers, what emphasizes the need to integrate ergonomics requirements into this development. The industrial designers and the mechanical technician were responsible by the operation of 3D printer and development of 3D printing of the emergency control room.

3.4. Choice of ergonomics methods and tools

Ergonomics methods were used to provide a way for the multidisciplinary team to use their experience and address ergonomics issues in the emergency control room design. The methods were selected based on what kind of information the methods provide, on what kind of information the designers could use and on what ergonomics methods could generate more predictive databases.

4. RESULTS

The multidisciplinary team decided to use the guideline NUREG 0700 [11] and the standard ISO 11064 [1] as references. The international standard ISO 11064 specifies procedures and processes to be followed in the ergonomics design of control rooms. It determines the general ergonomics requirements for ergonomics design of control rooms. NUREG 0700 provides one section dedicated to the human-system interface elements, one dedicated to specific systems and another one dedicated to workstation and workplace design.

The multidisciplinary team decided to use the following requirements in the design of the emergency control room:

- Localization of the principal control room: fifth floor of the nuclear reactor building
- Localization of the emergency control room: first floor of the nuclear reactor building
- The composition of the operator crew: two operators
- The area of the emergency control room: 27 m^2
- Amount of entrances, exits and escape routes: 2
- Amount of emergency console: 1
- One emergency console with three video display unit, one hardware panel, three keyboards and mouse
- In the area of the emergency control room is included a rack of the reactor protection system rack
- In the area of the emergency control room is included a rack of the post accident monitoring system
- In the area of the emergency control room is included a rack of the reactor control monitoring system
- In the area of the emergency control room is included place for CCTV monitor and overview displays
- In the area of the emergency control room is included place for bookshelves
- In the area of the emergency control room is included place for printers
- In the area of the emergency control room is included place for fire system announcer

The figure 1 shows the localization of the main control room and the emergency control room in the nuclear reactor building.

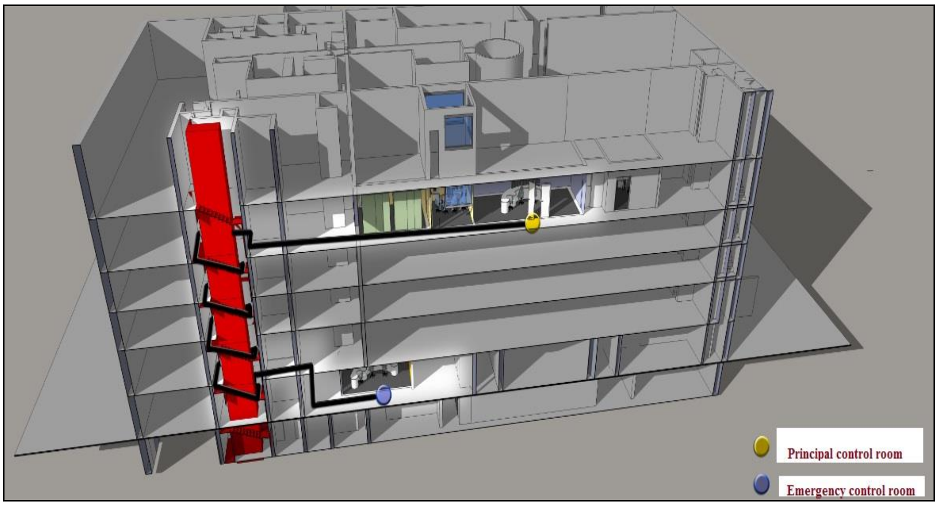

Figure 1: Principal control room and emergency control room

The figure 2 shows the mockup of the emergency control room. The mockup was developed through the methodological framework defined in item 3 and using the 3D printer. The overall results showed a positive and significant contribution of participatory ergonomics. The figure 3 shows the top view of the emergency control room.

Figure 2: The front view of the emergency control room

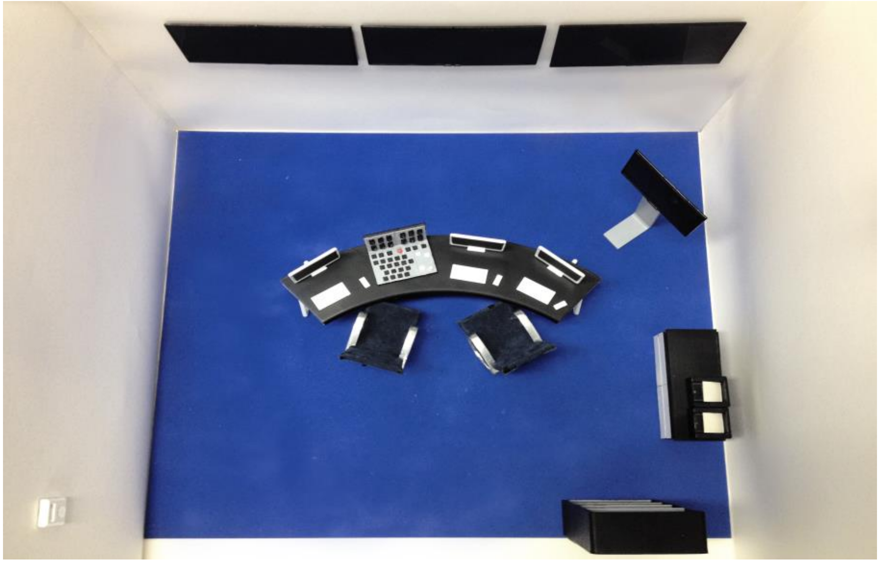

Figure 3: The top view of the emergency control room

The mockup showed in figure 2 and figure 3 illustrates the emergency console with three video display unit, one hardware panel, three keyboards and three mouse; two chairs; three overview displays/closed circuit television (CCTV) positioned on the wall; one overview display used only for operation positioned on the ground; one bookshelves; fire system announcer and two printers on a rack.

5. CONCLUSIONS

The use of participatory ergonomics in the nuclear industry presents many opportunities for improvements with regard to system effectiveness, efficiency and safety. This approach reflects the importance of having a group of professionals from diverse fields of knowledge and with different technical capabilities, those provide decisions, take actions, work on the coordination, and promote communication among the members, assisting in the choice of ergonomics methods and definitions related to the design goals. Plant significant event reports have root causes related to the human errors. Consequently, attention is given to a human factor engineering program to ensure that control room design is consistent with the cognitive characteristics of operators, enabling a compatible human performance with the desired mission and minimize human error. The design solutions were made considering the appropriate use of the control room, emphasizing that work practices should be based on the notion that the human is the most important link in complex socio-technical system. To achieve this goal, a mockup design provides the mean for verification and validation process of the control centre design. A mockup is used for conceptual evaluation, rapid prototyping, experts decision-making and for the verification and validation of the design features of the control room. The methodological framework applied to this paper made possible the use of human factors standards and the participation of a multidisciplinary team in the development phase of the emergency control room. Using the information gathered from standards and from the multidisciplinary team a 3D Sketch and a 3D printing of the emergency control room were created.

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