IMPROVEMENTS ON HUMAN-MACHINE INTERFACE OF ZPRL

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ABSTRACT

TMI accident showed that operator performance is critical to system safety. Human-machine interface (HMI) is one of the factors that will affect human performance. Currently, the Instrumentation and Control (I&C) system of Zero Power Research Reactor at Lung-Tan (ZPRL) is going through an upgrading process. This I&C modernization program encompasses replacement of analog control with digital control. Computer-based HMI for nuclear systems, which consolidates data from many indicators and controls into a confined display screen estate, poses a new challenge to human-system interface designers. Therefore, the development of computer-based HMI requires a thoughtful procedure of human factors analysis, design and evaluation in order to ensure that operability and maintainability requirements are met. The purpose of this paper is to develop the HMI of ZPRL according to the human factors engineering (HFE) review guideline prescribed by NRC (such as NUREG-0711, NUREG-0800 and NUREG-5908). Through this effort, human factors requirements can be incorporated into the design of the HMI of ZPRL with the human reliability analysis (HRA). Lastly, the verification and validation (V&V) process of HMI is performed with dynamic simulation for ZPRL.

INTRODUCTION

The ZPRL is a 30Kw research reactor located in Institute of Nuclear Energy Research (INER) in Taiwan. ZPRL reached its first criticality in 1971. The analogy I&C system is now facing obsolescence problem and has difficulty in obtaining parts. Therefore, a program to upgrade the I&C system (Yenn and Shieh, 1996) is underway. The digital control system has gone through the safety review process and gets the operation permission from Atomic Energy Council (AEC) in 1995. This utilizes four computers in providing data acquisition, operation of control console, controller and auxiliary module. They perform the automatic control, fault tolerance and screen display functions. The display and control functions are function-orientated design.

The purpose of this research is to study the improvement of the HMI in the main control room console's screen display for ZPRL. The design of HMI is based on the Human System Interface implementation plan of I&C system of Lungman project in Taiwan, regulations of NUREG-0711, NUREG-0800, NUREG-5908, and the human ergonomic design theory (Vincente and Rasmussen, 1992, Dinadis and Vincent, 1996). Following a walk-through with the operating crew, the HMI requirements are subject to the uniformity, distinctiveness, simplicity of display of all important safety parameters and HFE design principles (Woods, Hill, Boyer and Morris, 1992). The improvement of HMI of main control room is targeting the HFE design of screen display of the digital control system. It groups the critical plant safety variables in normal and abnormal operations, using graphic and perceptual aids to display the status of the whole system concisely and effectively. It is not only to meet the HFE requirements and safety evaluation of ZPRL, but also provides the confirmation of HRA through system dynamic simulation test.

DEVELOPMENT OF HUMAN MACHINE INTERFACE

To achieve the improvement goal of HMI, the HFE program model, prescribed in NUREG-0711, was adopted in the HMI design process. Moreover, the important human ergonomic design principles were incorporated into the design. Firstly, the primary goal of the interface is to support operator's tasks in ZPRL. The sequence of the screen flow is compatible with the task structure. Secondly, appropriate display formats are employed to facilitate the operator's information processing. Thirdly, "direct manipulation" interface design enables operators to control the system easily and visualizes the effect of their control action. Fourthly, the HRA can provide valuable insight into desirable characteristics of HMI design. Following the implementation, the V&V process is performed with dynamic simulation.

Task Analysis

To analyze the ZPRL operational tasks (Yenn and Hsu, 1997), the HFE team and the operating crew reapply the ZPRL operation procedure. The ZPRL operation procedure can be broken down into two modes: start-up testing and formal operation. To analyze the steps of both modes, we describe the purpose of each step, the presentation of the information, the action, the feedback, the cause of problems and the solution to the problems. This effort can identify the task requirements of ZPRL that assist in achieving higher safety and availability.

Human Machine Interface Design

The HMI design is systematic. This design process consists of the following steps: (1) Incorporate conversations and interviews with the operators into the design style and implement ergonomic design theory to show the limitation of the system; (2) Design with graphic flow charts and information diagrams to ensure operational tolerance and support; (3) Design with consistent information and command language to ensure the input consistency and simplicity; (4) Design with flexible detail process to reduce the workload of the operating crew and meet the tolerance of the acknowledgment (??); (5) Verifying and testing with dynamic simulation to ensure the reality of the interface design.

The interface design utilizes the following tools: (1) Apply object and graphic to distinctly information display (Carswell and Wickens, 1987, Wickens and Andre, 1990); (2) Feature logic top down layer of interface to help decision making; (3) Group the important information and the outline of the octagon shape attracts operator's attention; (4) Pop-up windows can link information; (5) Provide complete information of operation procedure and the administration control. (??)

The graphic design is divided into three formats: start-up, testing, and operation, based on the task analysis and the two operation modes. The purpose of the first start-up screen is to identify the operator, record activities, and help the administration control. On the test mode, It checks with manual, and the progress of the test will automatically produce a statement of results, which will provide adequate feedback information for the operator and the maintenance engineer.

In the operation mode, the start-up, control and scram of the reactor are all operating under the same window screen (Figure 1). There are four layers from top down to display the relationship of the whole system. The top layer with a ZPRL logo provides the first-hand alert, if there is any abnormal situation. From this screen you can click and pull down the octagon screen (Figure 2). This circular profile can display eight critical safety variables simultaneously. The second layer shows eight ZPRL emergency shutdown parameters' indicators. They can point out the origin of the emergency signal. From the abnormal display of the water temperature, water level, and high voltage values of detector, the operator can pull down the screen showing the object and status. The third layer displaying in the middle of the screen is the power change of reaction grouping by their function. The semicircle represents the period of reactor. At the right side of the screen, there are reactor information from three different detectors, describing the complementary result by number, color and object. The fourth layer displaying is the reaction of the control rod from the operator, including manual, automatic, and shutdown operating, the position of the control plate. The emergency signal makes it easy to know the status of the computer. By clicking the SCAN CONTROL, it can pull down the trend variable display. It also provides a frozen screen when the reactor is shutting-down that helps administration control.

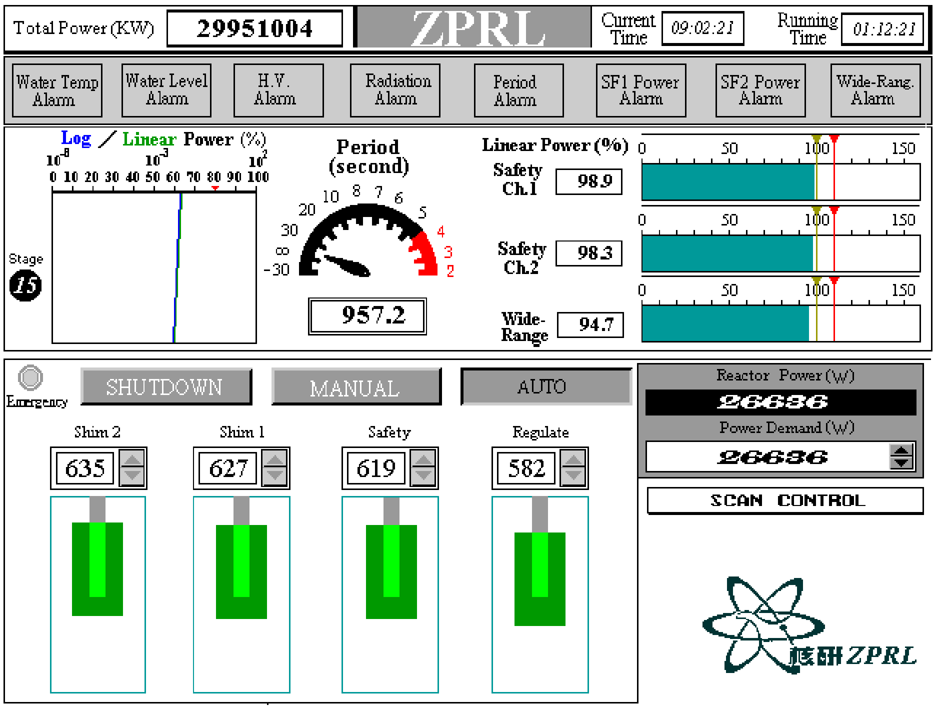

Figure 1 Operation screen of HMI for ZPRL

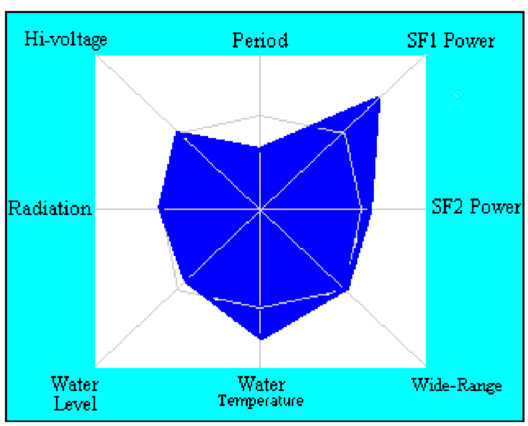

Figure 2 The circular profile displays eight critical safety variables

After the task analysis and HMI design, an operational procedure of ZPRL is developed. That development is based upon the HMI requirements, critical human actions identified in the HRA, initiating events to be considered in the emergence of procedure.

Human Reliability Analysis

The purpose of the HRA is to estimate the impact of human error on reactor safety. The HRA adopts the HEART method. HEART was developed by William (1985). Basically, HEART is a quick and flexible HRA tool. It is very easy to use and provides human error-reduction measures. Our application of HFE improvement, based on human error assessment and reduction techniques (Humphreys and Kirwan, 1988), is as follows:

1. Subject: information display of the main control room for ZPRL
2. To identify the event: reactor trip logic
3. To identify the general task: routine, highly-practiced, rapid tasks involving relatively low levels of skill
4. To choose four factors of Error Producing Conditions (EPC), which are as follows:
   - poor system/human interface
   - designer/user mismatch
   - poor instrumentation or procedures
   - inadequate checking
5. To assess the nominal likelihood of Human Error Probability (HEP)
6. To calculate the distribution of EPC.

The experts of human reliability use their expertise and experience to choose the most applicable proportion of the effects on experimental operation to evaluate the effect of the various factors that caused the human error. This result is used as the basis of improvement of the HMI. Before proceeding to design, the human reliability array is used to understand the most-needed areas of HMI improvement of the main control room at ZPRL. Then the previously mentioned HMI design and procedure are used. This process involves operating crew with repeated communication, discussion, evaluation, modification, and assessment. HRA's results prove that HEP was reduced to nearly 1/5 after adoption of this design. From using the EPC, distribution array, and finding the poor system-human interface and the design/user mismatch, the figure also drops to more than 10% after the results.

HMI Verification and Validation

The HMI design of the digital control system also goes through a V&V process. The major V&V activities are HMI specification requirements verification and functionality validation. Following the standard NUREG-0711 procedures for HMI V&V, an independent team conducts the traceability analyses to verify the HMI requirements. The HMI design is checked against the requirements of safety evaluation report and technical specification of ZPRL, NUREG-0800 and NUREG-5908. A checklist is used to ensure consistency, compatibility, and understandability of key HMI specifications. Further, using dynamic simulation validates system performance and achieves reduction of human error.

A full-scope dynamic simulation for the HMI design is developed with graphical language. It utilizes Labview 4.01. Subjecting to the normal, abnormal, and scram operating conditions, the task performance of ZPRL has been validated through this dynamic simulation. It includes repetitive practice sessions to train the operator to deal with emergency procedures and to familiarize the operational response about information display. The information processing work load was reduced to nearly 1/5.

CONCLUSIONS

HMI design at ZPRL has won the acceptance of the operating crew after its implementation. This paper uses the digital control system of ZPRL as a platform to achieve the goals and make the operation reliable and easy to control, reducing the probability of human error. This result is going to apply for design-change permission to the AEC. After approval, it will be adopted in the digital control system at ZPRL. Although ZPRL is a small reactor for research, it has all the necessary controls. The development of this project has a firm grasp of all the principal specifications of HMI in its control room to help the domestic nuclear energy industry. This practical experience will extend to renovate the main control room of nuclear power stations, such as the Lungman Project at the Taiwan Power Company or the reconstruction work of Taiwan Research Reactor (TRR) in INER.

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KEY WORDS

Human-Machine Interface, Human Factors Engineering, Human Reliability Analysis, Human Ergonomic Theory