Investigation of Potential Operation Issues of Human-System Interface in Lungmen Nuclear Power Project

C. F. Chuang and H. P. Chou

Abstract-- **The Lungmen Nuclear Power Project (LMNPP) with 1350 MWe twin units is the first advanced boiling water reactor (ABWR) project in Taiwan. Video display units are the main human-system interface for operator to manipulate, i.e. so-called "soft" control, and to know the status of the equipment and plant information. Several concerns have been identified as compared to hard controls. These concerns led us to conduct an investigation of the operator's performance and the potential issues about operator's teamwork. The investigation results show that the most important task is to establish an intensive training program to address the knowledge and skill requirements of the operators to meet the task characteristics and the responses of the plant processes..**

I. Introduction

Control rooms have progressed through three generations in the last thirty years. Three Mile Island (TMI) accident and Chernobyl accident revealed that the operator's performance in main control room (MCR) is greatly related to the safety of the whole NPP. The lessons learned from the review of the accidents, have been incorporated in the design and operation of human-system interface (HSI) at all nuclear plants.

One of the most significant changes in control rooms in the last two decades has been the increasing use of computers in plant monitoring and control. The control room design has been rapid changed as increased computerization and automation have been incorporated. Although the design of digital controls and HSI reflect the TMI lessons learned; operators should be routinely trained on the plant simulator to be familiar with the plant response for all abnormal plant conditions. Therefore, good human-machine interaction through the control elements and information displays is absolutely necessary for safety operation of NPP.

Information has been largely presented on computer driven displays. A control room that uses computer driven displays for information presentation and controls, as opposed to using hardware components, is sometimes referred to as a 'soft' control room. [1] Increased computerization has made it possible to provide an interactive HSI through video display units (VDUs) to monitor and control most operations.

The LMNPP under construction in Taiwan is an Advanced Boiling Water Reactor (ABWR) with 1350 MW electrical output. The I&C system is digitalized, and extensively adopts multiplexing network technique and software application. Hence, the main control room design, the operation information display manner and operator control manner are extremely different from traditional Boiling Water Reactor (BWR). The important information are highly integrated and used by the operators through video display units (VDUs). Nancy G. Leveson [2] expressed the concern of the safety for human-machine interaction. It brings the control freedom; on the other hand, it also requires proper review procedures and training for the operators.

With automation increasingly taking over routine tasks, operators will use less skill-based and rule-based behavior and more knowledge-based behavior. Operator training will need to focus less on building skills and rules for action and more on general ability to understand how the system functions and to think flexibly when solving problems.[3] Because effective action may require teams, each worker may need to be familiar with the tasks and skills of other workers.[4]

A top-down Human Factors Engineering Program Review Model (HFE PRM) was also developed to assist the evaluation of modern soft control room. The model was adopted in "NUREG-0711 ： Human Factors Engineering Program Review Model" [5] and became the review criterion for digitalized control room of newly constructed NPP such as LMNPP. In addition, IAEA published the 387th technical report "Modern Instrumentation and Control for Nuclear Power Plants: A Guidebook" in 1999 [6].

The present methodology was based on these studies as stated in section II. Reactor water cleanup system (RWCU) and main control room were chosen for case studies. Section III presents the findings of important HSI issues. Finally, the solution for the potential problems in LMNPP operation are addressed and summarized as the conclusion of this research.

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II. Overview of LMNPP HSI Design

A. Main Control Room

The main control room includes Wide Display Panel (WDP), Main Control Console (MCC), and Shift Supervisor Console (SSC). The major human-system interface is Video Display Unit (VDU). Totally 45 VUDs are in the control room, 42 of them with monitoring and controlling function are located on the Wide Display Panel and Main Control Console; the rest three units only with monitoring function are located on the Shift Supervisor Console. Among the 42 VDUs with monitoring as well as control functions, 13 units are safety related to monitor and control all safety systems; the other 29 units are for non-safety systems.

The alarms, displays, and controls in the MCR are classified into two categories as "fixed position" and "variable position" by their importance. It is very different from the spatially dedicated "fixed position" single design used in the traditional NPP. Although the most important alarms, signal displays, and control switches are still with "fixed position" design, but the large amount of components is "variable position" design and goes through the VDUs to interact with operators.

B. VDU Display Format and Hierarchy

The VDU screen is divided into three regions, "Title Bar", "View Area", and "Navigation Bar Area". "View Area" almost occupies the whole screen, all the important information is displayed in this region. "Navigation Bar Area" is located at the right long and narrow region; this area can contain 2×10 buttons at most. All the 20 buttons are not necessary used at the same time. The color of the button turns gray when it is not allowed to touch.

There is an on-line operator's manual. It is the "Home page" of the whole operation screen. The page separates into 15 blocks, each block contains 89 items. Ninety-eight systems can be controlled from this page. In total, there are nearly 1000 operation screens with the hierarchy of three levels which brings about the concern that if the number of operation screens are much too many for the operators to handle and navigate.

At present, the LMNPP simulator has only 50 items, which can only control 56 systems. In the early training phase of LMNPP, the operator's training program is carried out in this simplified version. Although the simulator will be updated to be identical as the MCR eventually; the impact of this difference still needs to be evaluated in the future.

C. Alarm Design

In the alarm design, Priority, Filter, and Suppression are the newly added functions for LMNPP. According to the importance of alarm, there are four levels of priority. The alarm units for system damage or automation logic action are classified as priority 1 or 2; these alarms will display on the system alarm window of WDP when activated. Besides, for effectively utilizing the feature of handling massive information by digitalized equipment, most of equipment status is expressed as priority 3 and 4. However, the detail information can be inquired by VDU.

III. Methodology

The present investigation for HSI of LMNPP is based on the soft system methodology given in Ref. 3. The procedures are listed as follows:

1. To identify the existing practical problems in the system
2. To abstract them to define the cause of the problem
3. To construct the concept model for resolving the problems
4. To propose the plan for resolving the problems

We have applied the procedure to RWCU and MCR of LMNPP. To stress the difference of the modern design, we compared with similar systems in traditional BWR design. The Taipower's Kuosheng NPP (KSNPP) was chosen as the contrast case for comparison. We focused the investigation on human-machine interface design in both plants according the procedure listed above. The ultimate goal is to identify the potential issues and to develop the measures to eliminate or reduce them.

Along the investigations, we visited both NPP sites to compare designs in terms of room space, panel allocation, operation information (such as Indicators, Alarms) display manner, control elements, and color management. We interviewed the operators with the questionnaire shown in Table 1 to obtain a more detailed expression of the problem.

Table I
Questionnaire

Items	List of Concerns
#1	How do the operators distinguish the difference between the MCR of LMNPP and that of the traditional NPP before the simulator reaching?
#2	There are about 1000 screens which may be distributed on 45 VDUs. Is the information display inconvenient for the operators? How to search quickly? How to share the information?
#3	Regarding the postulated abnormal events in PSAR chapter15, how to present the information in the screens to notice all the operators? Does it induce overload for mental model?
#4	The color management in LMNPP is different from that of traditional NPP, how do the operator adapt? Do they adapt to it? Does it induce overload?
#5	Does digitalization induce any control behavior variation of individual or operation team? Does it affect the training or the licensing?
#6	Lot's of information is hidden, such as alarm, how to search it quickly?
#7	We are planning to compile the draft questionnaire of investigating the operator's opinion for digital control, what's your opinion?

We performed the investigation regarding to the operator mental mode and the adaptability and manipulation of the digitalized human- machine interface by interviewing three trainees who have taken ABWR simulator- training courses. We also reviewed the material brought from Japan as the reference for future training and evaluating the LMNPP operators.

IV. Results and Discussion

A. Findings on RWCU comparisons

We compared the HSI of RWCU between the two designs in terms of system process, control element, information display, and the operator's operation manner.

For the RWCU system, the overall HSI design of LMNPP is better than that of traditional KSNPP. In traditional design, the operator has to reach the panel for control and the control element is operated directly without any protection. It can be operated from both directions (start or stop) without any constraint. In LMNPP, if the operation is prohibited, the control button will be "gray out" automatically. Hence, the risk of operator mistake can be reduced; the design to prevent fault action is better.

In the traditional design of KSNPP, the operator can control several equipments simultaneously. In LMNPP, the operator can only control equipment one at a time from one VDU. In the LMNPP design, the equipment can be tagged out for maintenance directly from VDU, which means the configuration of the equipment will be easily changed, but this is not for KSNPP.

B. Findings on Control Room HSI

After interviewing the experienced operators and the operation managers by the questionnaire, as given in Table 1, for both KSNPP and LMNPP, the following common consensus are obtained.

To establish the usability strategy of hard switch and soft switch in MCR is urgent. The MCR design in the LMNPP tends to only operate the hard switch in emergency situation. It is also found that the VDU usability strategy in various operation modes is similar to traditional control room.

Although the modern HSI design is user friendly, there is still a need to enhance the operation team training for handling the abnormal situation. In order to enhance team work, the oral communication and point-and-call action are the important lessons for the operators to coordinate their understanding of what is wrong with the power plant and subsequently how to deal with it, than with the previous system.

In addition, what we highly concern is that hundreds of displays and controls are only viewed through a limited number of VDUs. There must be a cognitive cost for accessing information by display navigation, i.e. concerns on the operator's performance include the demands of memorizing display locations, the inability to quickly access needed information, and delays in accessing needed displays. The LMNPP HFE V&V will verify them.

C. Interviewing with the Trainees

Nowadays, Japan is the only place that has the ABWR physical plant in the world. To assure the safety operation of LMNPP in the near future, we have sent a task force to learn the operation experience and to take the training course in Japan. After interviewing with these trainees and reviewing their reports and the material brought from Japan, the major observations are given as follows [7].

The amount of hard switches in Japan K6/K7 plant is more than that in LMNPP. The network in LMNPP is also more complicated. At full power, the layout of displayed systems on the CRT in K6/K7 plant is similar to the layout in traditional control room. With automation increasingly taking over routine tasks, the K6/K7 plant operators' role change from active control to monitoring. However, the operator must be familiar with the automation logic and the procedure for changing to manual mode while the automation malfunctioning. Japan's utility also developed a performance evaluation radar graph to enhance team work.[7] With this evaluation graph the optimum operation team can be identified. It was then adopted by LMNPP for later training use.

V. Conclusion and Suggestion

Regarding to the main control room design in LMNPP, the operation information display manner and operator control manner are extremely different from traditional Boiling Water Reactor (BWR). The important information, no longer through spatially dedicated switches, alarms, and meters, are highly integrated and used by the operators through video display units (VDUs). The control and information presentation manner in VDUs provides more convenience and control freedom to operators.

The present research observed that if the control freedom is not properly constrained, such as improper VDU usability, it would be the chaotic source of control room and potentially threats the operation safety, particularly, at the time of any changes or anomalies in the process of the power plant due to the lack of shared information available to the operators and their inability to keep each other informed of their current knowledge of the system. Therefore, to establish the chaotic source reduced strategy and an intensive training program to address the knowledge and skill requirements of the operators to meet the task characteristics and the responses of the plant processes are the most important topics at this moment. The VDU configuration strategy, as provided by K6/7 will be a useful reference for LMNPP. Furthermore, the strategy has to be verified during the LMNPP HFE V&V.

After the investigation we concluded those HSI issues probably affecting the safe operation in the LMNPP. The operator's role, operation skill, mental mode and VDU usability strategy require the utility to allocate more resource to develop a better training program. It is also important to develop a performance evaluation strategy for teamwork in the area of Computer- Supported Cooperative Work (CSCW).

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VII. REFERENCES

[1] Asaf Degani, Everett A. Palmer and Kristin G. Bauersfeld, " Soft Controls for Hard Displays: Still a Challenge", San Jose State University Foundation , San Jose, CA ,1992.

[2] Nancy G. Leveson, "Safeware－System Safety and Computers, A Guide to Preventing Accidents and Losses Caused by Technology", Addison-Wesley Publishing Company, 1995.

[3] Jenny Preece, Yvonne Rogers, Helen Sharp, David Benyon, Simon Holland and Tom Carey, " Human-Computer Interaction", Addison-Wesley Publishing Company, 1994.

[4] Samuel G. Charlton, Thomas G. O’ Brien, "Handbook of Human Factors Testing and Evaluation", 2nd Edition, Lawrence Erlbaum Associates, Mahwah, New Jersey,2002.

[5] O’Hara, J., Higgins, J., Stubler, W., Goodman, C., Eckenrode, R., Bongarra, J., and Galletti, G., "Human Factors Engineering Program Review Model (NUREG-0711)", U.S. Nuclear Regulatory Commission, Washington, D.C., 1994.

[6] Technical Report #387, "Modern Instrumentation and Control for Nuclear Power Plants: A Guidebook", International Atomic Energy Agency(IAEA), Vienna, 1999.

[7] H.J. Fan, "Trip Report for The Training Course in K6/K7 Simulator, TECRO, Japan", Lungmen Nuclear Power Station, 2003.