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DEVELOPMENT AND VALIDATION PROCESS OF THE ADVANCED MAIN CONTROL BOARD FOR NEXT JAPANESE PWR PLANTS

M. TANI, K. ITO, M. YOKOYAMA, M. IMASE, H. OKAMOTO

Abstract

The purpose of main control room improvement is to reduce operator workload and potential human errors by offering a better working environment where operators can maximize their abilities. Japanese pressurized water reactor (PWR) utilities and Mitsubishi group have developed a touch-screen-based main control console (i.e. advanced main control room) the next generation PWRs to further improve the plant operability using a state of the art electronics technology. The advanced main control room consists of an operator console, a supervisor console and large display panels. The functional specifications were evaluated by utility operators using a prototype main control console connected to a plant simulator.

1. INTRODUCTION

It is important to provide a Human-System Interface (HSI) system with which operators can easily pick up appropriate information among a large number of plant process parameters and correctly identify the plant state.

The design of main control room in Japan has been continuously improved from conventional single large board with hard-wired indicators and switches to functionally divided boards with CRTs as major information source. (see Refs. [1-2])

A fully digital I&C system including the advanced main control console is planned for the next Japanese PWR plant with a view to achieving increased safety, reliability, operability and maintainability.

It is desired to improve the safety and efficiency and to construct the HSI system suitable to the fully digital I&C system so that operators can correctly perform their tasks; diagnosis of plant problems, active planning and implementation of control actions.

A touch-screen-based main control console, which has the following features, has been developed to meet the above-mentioned objectives.

- Full-time sit-down-operation console for reducing monitoring areas and traffic.
- Touch operational HSI system with CRT and Flat Display panels (FDP).
- Plant information presentation, which should be shared by the shift supervisor and operators using large display, panels (LDP)
- Automation of high workload monitoring tasks such as plant trip, and presentation of its results.
- Suitable space allocation among large display panel, operator console and shift supervisor console for smooth communication among all the operators.
- Functionally distributed computer systems architecture for enhanced maintainability and system reliability.

This paper describes the design concept, enhanced operability features, system configuration and evaluation results of the advanced main control console.

2. ENHANCEMENT OF OPERABILITY

The recent design improvement trends of main control board are obviously directed toward the soft operation utilizing computer driven HSI devices. The benefits of the soft operation are to supply relevant process information necessary for the implementation of control as well as providing appropriate process parameters for facilitating tasks, in addition to saving spaces of instrumentation and Control switches. The advanced main control boards consists of an operator console, a supervisor console and large display panels.Figure 1 shows the configulation of the boards.

The advanced main control console also enhances the operability by taking advantage of the soft-operation as described below:

2.1. Touch operation

Control actions are composed of check process of their ready-condition before implementation, monitoring process of control feedback parameters (direct control and its side-effect parameters), and verification process after implementation. In order to improve the operational quality by providing all the necessary parameters for control actions, control switches and relevant parameters are integrated onto the same control display. In addition to the integration of control switches and relevant parameters, automatic check functions for implementation start are been introduced.

2.2. Automatic verification and display

In order to reduce peak load in the Trip/SI situation, automatic verification of system level interlock and sequence actions are performed.

The verification results are automatically presented on the CRTs, the FDPs and the LDP.

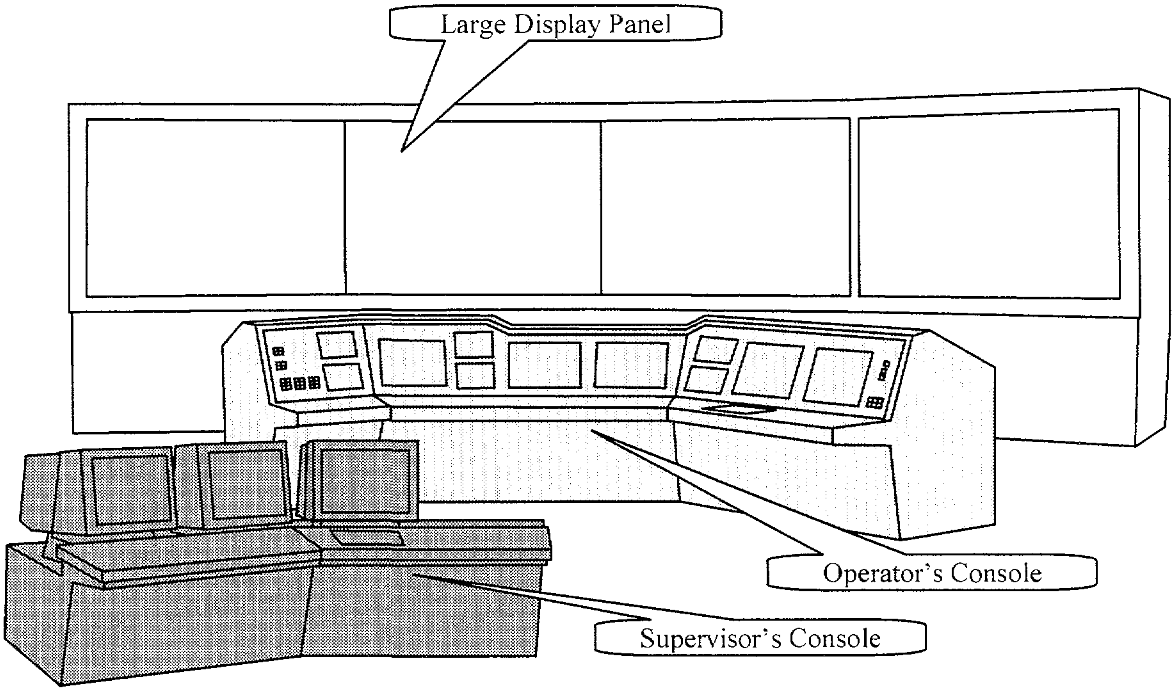

FIG. 1. Main control board configuration.

2.3. Inter-connected display request

All the control and monitoring displays are inter-connected in terms of functional and/or operational relationships and relevant displays can be readily requested by touching the keys presented on the rim of the displays. Figure 2 shows an example of integration monitoring and controling effect.

3. ALARM PROCESSING AND PRESENTATION

An alarm handling system that dynamically prioritizes alarms is used for avoiding information overflow and to facilitate plant state identification. The prioritized alarms and their relevant process parameters are provided in the graphically presented plant systems on the LDP with 3-level categorized color coordination. Individual and/or breakdown alarms are also presented on CRTs and FDPs with the priority categorization.

4. DESIGN RULES FOR TOUCH DISPLAYS AND LARGE DISPLAYS

Prior to adopting the touch-operation, various soft switches were tested, which included mouse, track ball, and touch screens, in terms of pointing accuracy, manipulability, and applicability to safety systems.

The manipulability of soft switches were tested in an experiment using a control system simulator. Equal manipulability between soft control switches and hardware control switches were verified for the steam generator feed water valve switch operation, which requires the most rapid and accurate manual control in the operation of PWR plant.

In order to establish appropriate soft switch button size, touch input test was performed experimentally, adopting touch input success ratio for a target area, touch point spatial distribution, and touch action time distribution as the evaluation indices. A control display configuration rule was specified based on these experimental results.

The large display configuration rules were also specified based on the examination concerning the distance and angle from the operator position, character and symbol size, and information density. An example of control display is shoown in Fig. 3.

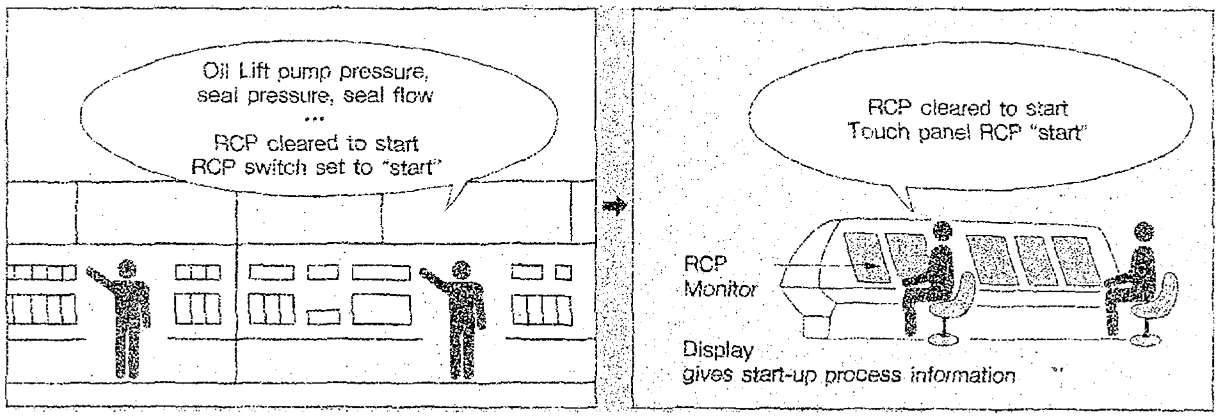

FIG. 2. Enhancement of operability.

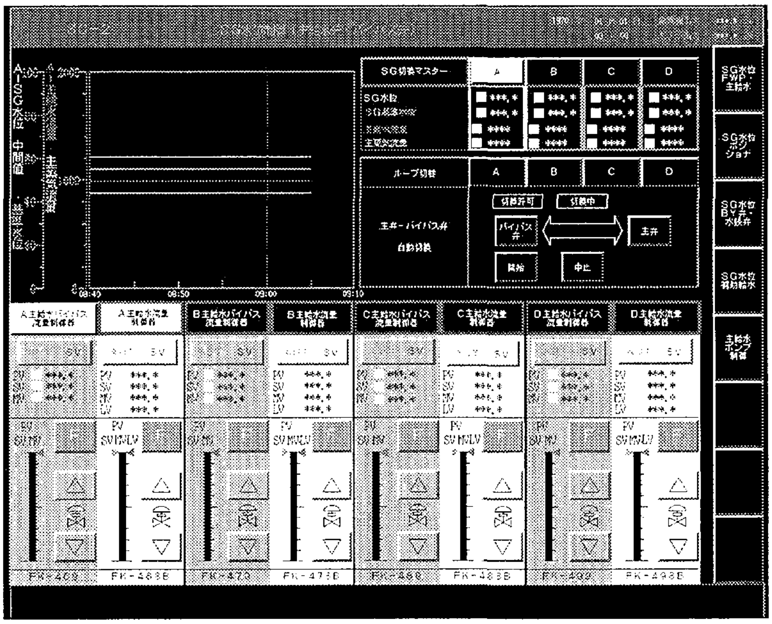

FIG. 3. Integrated displays for control & monitoring.

5. COMPUTER SYSTEM ARCHITECTURE FOR HSI SYSTEM

Because of its high reliability of using simplified software system and distributed maintainability, a functionally distributed computer system architecture, was adopted for HSI devices in which the LDP processors, integrated monitoring and control CRT processors, alarm processors, safety grade integrated monitoring and control processors are combined with a high speed data link system.

In terms of control function assignments between HSI devices and digital process control and protection systems, only the control request input function (i.e., input button function) was assigned to the HSI processors considering the software verification and validation.

Figure 4 shows the architecture of HSI systems.

Highly reliable software, which is as simple as the software of protection system, was adapted to the safety grade HSI device processor. Although control signals are separated from non-safety HSI device processors, display request signals can be input from non-safety processors for smooth monitor and control task procedure.

The two types of data link systems were used of data passing between the HSI device processors and the digital control and protection systems to meet the requirements for the process response time and the transmission data volume. The high-speed dataway systems are used for monitoring date transmission because of its large size data volume, and the multiplex systems for control data transmission because of its rapid response time.

6. OPERATOR WORKLOAD AND HUMAN ERROR PROBABILITY EVALUATION

The HSI improvement level, in comparison with the main control board of the latest plant in operation, was quantitatively evaluated in terms of operator physical/mental workload and potential human error probability.

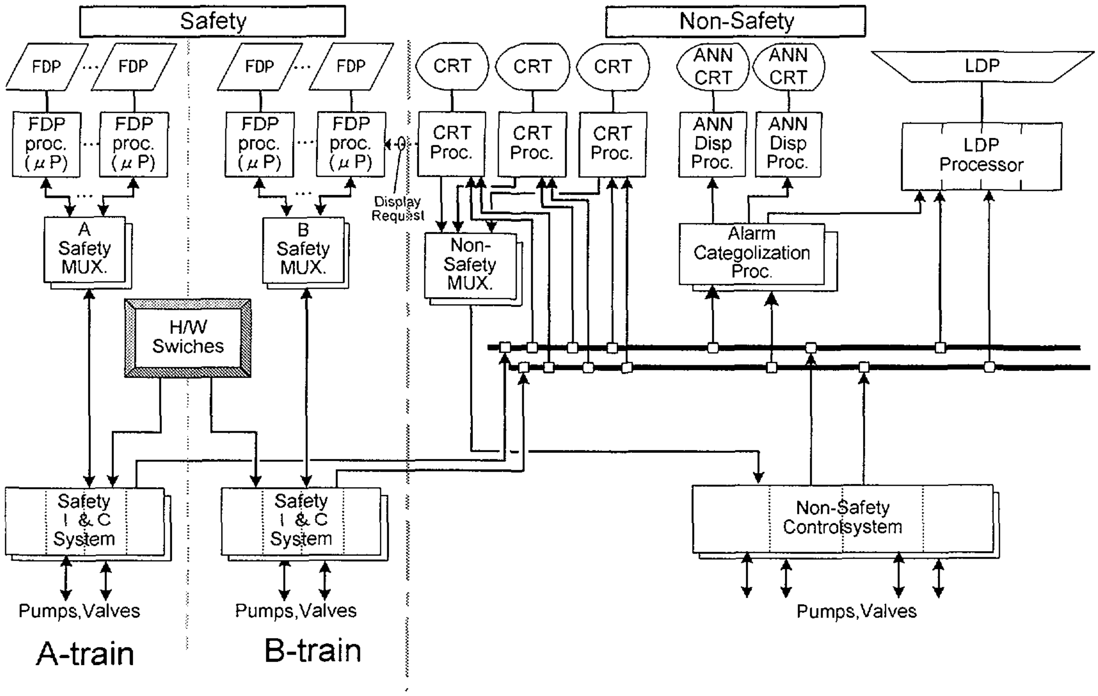

FIG. 4. HSI device processor architecture.

The physical workload was compared between the advanced main control console and main control board of the latest plant in operation, using the number of monitoring and control actions during accident operations as evaluation index.

Figure 5 shows the acuumulation method of mental workload in the operator model human processor model (see Ref. [3]).The mental workload was also compared similarly using a human information-processing model.

The physical and mental work load level of the advanced main control console appeared to reduce by about one third. Estimated potential human error on the other hand, appeared to be reduced by about one fourth. THERP (Techinique for Human Error Rate Prediction) were used in the valuation (see Ref. [4]).

Their results indicate that the integration of control switches and their relevant monitoring parameters, the inter-connected display request method, and the automatic verification function contribute greatly to the reduction (Table I).

7. VALIDATION TEST

In order to apply the advanced control console to nuclear power plant operation, the fully man-in-the-loop verification and validation (V&V) test has been planed. The design of the MMI shall be verified and validated with adequate facilities and resources at each phase of V&V phase in participant of the user (i.e. shift operators).

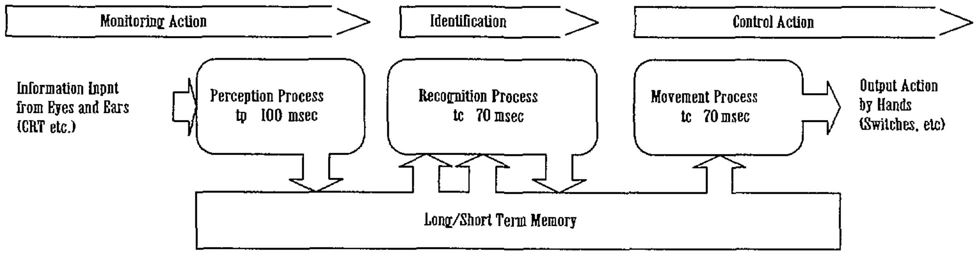

FIG. 5. Operator information processing model.

TABLE I. ANALYTIC EVALUATION RESULTS

Design goal	Evaluation method	Result (compared with improved control board)
Woakload	Operator Sequience Diagram	Abour 25% Off
	Model human processor	Abour 20% off
Human Error probability	THERP	Abour 25% off

The overall operability of the system was tested using a prototype advanced main control console connected to a full-scale plant simulator. This test was performed to confirm a shift supervisor, and one operator can monitor and control the whole plant under all plant conditions. The utility operating crews from different nuclear power stations joined the validation and went thorough under normal and accident conditions. The functional specifications of the displays integrated with control and monitoring functions, the display request method and alarm presentation system were validated by means of checking the implementation of operator's monitoring and control sequences defined in an operational manual. The validation results confirmed the improved operability of the advanced main control console.

In addition to the above mentioned operational sequence check, the operator's subjective rating was obtained through interviewing to confirm the qualitative evaluation points (e.g., cognitive process, control impression). The results suggested design goals of operability improvement were achieved.

8. CONCLUSIONS

It is believed that the advanced main control console would be applicable to the next Japanese PWR. The intermediate validation results confirmed the improved operability of the advanced main control console. The specification of the advanced control boards consoles will be finalized after continuing iterative validation tests. In the following validation phase, we also will attempt achieving further improvements of the advanced main control console. The effort will aim at the enhanced maintainability during the scheduled outage period and more advanced alarm presentation.

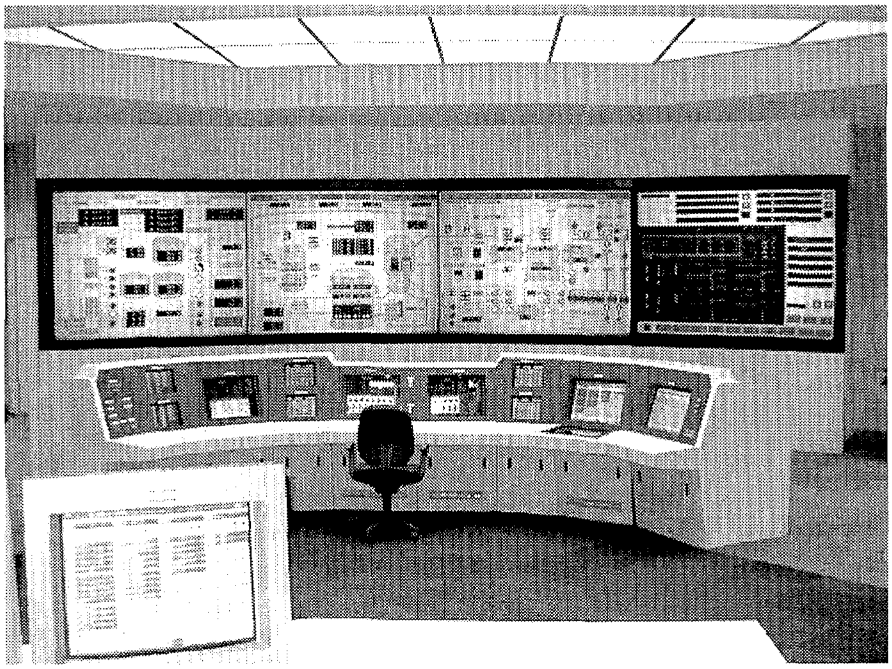

FIG. 6. Variation test facility of the advanced main control boards.

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