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The Advanced Main Control Console for Next Japanese PWR Plants

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INTRODUCTION

The purpose of the improvement of main control room designing in a nuclear power plant is to reduce operators' workloads and potential human errors by offering a better working environment where operators can maximize their abilities.

In order to satisfy such requirements, the design of main control board applied to Japanese Pressurized Water Reactor (PWR) type nuclear power plant has been continuously modified and improved.
According to the recently developed Improved main control board for Nuclear Power Plant, the reduction of operators' workloads, as well as of potential human errors has been practically reduced by introducing such as the following functions:

- CRTs become the main monitoring device,
- Functional classification of control boards (main board and auxiliary board) classified by the operation modes,
- Dynamic and prioritization alarm windows, etc.

In addition, the Japanese Pressurized Water Reactor (PWR) Utilities (Electric Power Companies) and Mitsubishi Group have developed an advanced main control board (console) reflecting on the study of human factors, as well as using a state of the art electronics technology.

In this report, we would like to introduce the configuration and features of the Advanced Main Control Console for the practical application to the next generation PWR type nuclear power plants including TOMARI No.3 Unit of Hokkaido Electric Power Co., Inc.

OUTLINE OF ADVANCED MAIN CONTROL CONSOLE

Background of Development of Advanced Main Control Console:
According to the conventional type main control board, it has actually reduced potential human errors drastically by adopting a CRT display as a monitoring device in comparison with the old-fashioned main control board.
The conventional type main control board had used hard-wired instrumentation and control switches. Therefore, it was restricted to supply relevant process information necessary for the implementation of control action, in addition to the operation area was too wide in view of the workload. This means that sitting down operation was practically impossible in all the operation modes.

The recent design improvement trend of main control board is obviously directed toward the soft operation utilizing a touch-screen-based main control console, which has the following features, has been developed;

(1) Integration of control switches and relevant parameters, onto the same display

(2) Fulltime sitting down operation consoles (compact-sized consoles)

(3) Enhancement the operability by taking advantage of the touch operation.

As a result, not only the potential human errors and physical workload have been reduced, but also the mental workload would be reduced.
Fig. 1 shows the basic configuration of the Advanced Main Control Console.

Configuration of Advanced Main Control Console:

(1) The Advanced Main Control Console is composed of the following components:
- Operator console is used for the monitoring and operation of the plant
- Large display panel is used for the presentation of the plant information,

which should be shared by the shift supervisor and operators.

- Shift supervisor console is provided exclusively for the leader of persons on duty.

(2) In order to ease getting the information at the operation and monitoring, as shown in Fig. 1, the shift supervisor console, the operator console and large display panel are placed before and behind with a certain interval.

In other words, the distance between the shift supervisor console and the operator console was arranged so that communications among the leader of persons on duty and the operators can be made effectively including their instructions, reports and conversations.

On the other hand, the distance among the large display panel, shift supervisor console and operator console was designed considering the clear visibility of information displayed on the large display panel from the operators sitting point.

Features of Advanced Main Control Console:

(1) Fulltime sitting down operation consoles (compact-sized consoles) have been applied for reducing monitoring areas and traffic.

(2) A touch panel was used so that a series of monitoring and operation work can be carried out on the same displaying screen.

Then the operation function was integrated with the monitoring CRT panel, except safety line system operating unit including the manual nuclear furnace trip and manual safety fuel injection (refer to Fig. 2)

In addition, for the safety line, anti-seismic designed FDP (Flat Display Panel) is scheduled to apply.

(3) By continuously displaying major information and alarm conditions on the large display panel, the integrated monitoring of the plant has become possible successfully. And the information on the large display panel shared by shift supervisor and operators.

As a result, a defect that information not displayed on the screen is concealed on the CRT and the FDP has been eliminated.

(4) In order to reduce the workload, as well as when an accident has occurred, automatic checking and automatic displaying functions by using a computer were performed, thereby the monitoring function has been strengthened.

(5) Fully digital I&C system, including the advanced main control console is planned for the next Japanese PWR plant. Then, in order to achieving increased safety, reliability, operability and maintainability, the integrated system architecture has been configured.

Enhancement of Monitoring Operation Function:
In order to reduce human errors and workloads drastically in comparison with those of the conventional type main control boards, it was prerequisite to strengthen the monitoring and operation function positively.
Then, some examples are shown below:

(1) Integration of monitoring and operation, into the same display (Fig. 2)
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 into the same control display. In addition to integrate of control switches and relevant parameters, automatic checking function* are been introduced.

*Automatic checking function:
At the occurrence of Trip or SI, the operators' workloads will become the peak by accompanied with the information processing work including the getting of relevant information, plant operation state confirmation, etc.
The automatic verification of system level interlock and sequence actions is performed. The verification results are automatically presented on the CRTs, the FDPs and the LDP.

(2) Systemization of displaying screen
The displaying screens of the CRT and FDP were composed systematically classified into the applicable functions, systems and lines.
Then a request touch area was provided partially on the screen (in the lowest stage and a right row), through which the operator can select the relevant screen by the one-touching action.

(3) Easiness of monitoring through large display panel (LDP)

The following functions were given to the large display panel so as to ease the monitoring work:

- Intensive displaying of important parameters as all times monitoring parameters in normal operation.
- Effective presentation of inter-crew common recognition information displayed on the large display panel.
- Pattern recognition depending upon information arrangement by using system graphic display.
- Easiness of alarm classification by using an important alarm prioritized displaying function.
- Timely displaying of information of computer check results (interlock and sequence actions of safety injection system)

VERIFICATION AND EVALUATION

In the course of the development of Advanced Main Control Consoles, first, a prototype was manufactured in the applicable development stage as shown below. Next, the prototype was connected to a full-scale plant simulator, and then, a status, which equal actual plant, was created. In this way, the utility operating crews from different nuclear power stations joined the validation and went thorough under normal and accident conditions.

Stage 1: Selection and validation of operation device (Executed by Only designers in 1989).

Stage 2: Development and validation of prototype (Executed in 1991. It was performed to confirm realization and function of advanced main control console by touch operation and large display panel and one operator can monitor and control the whole plant under all plant condition).

Stage 3: Validation test of the alarm system (Executed in 1997. For the above mentioned prototype machine, only the alarm system was improved and re-validated).

Stage 4: Validation test of mock-up for the actual plant (For the major purpose of establishing the standard specification, this was executed in the later period in 1998, and continued in the consecutive years).

By the way, the evaluation of human errors and workloads was made through the study of the evaluation method, and then, the desk evaluation was made. Such being the case, the development theme and its expression method, as well as the evaluation results are described as follows:

Touch Operation:

For the adoption of the touch operation method, in the Stage 1 of the above mentioned operation verification, it was performed. The verification was performed by operation of the feed water control valve actuation for the steam generator where the responsibility is the fastest and the operability is specially demanded in the course of the operation of PWR plant.

At the first, a simplified model of the feed water control system of the steam generator was manufactured.

Next, the manual changeover of the control valve was carried out both the hard- wired controller and the touch panel respectively.

After that, the setting time of the water level in the steam generator and the amount of overshoot were compared and evaluated.

As a result, it has been cleared that there is no difference between the touch panel and the hard- wired controller, as well as it has been confirmed that the touch operation is fully feasible.

In the selection of the touch panel device and the touch area size, the succeeding rate of the touch was collected, and then, the selection standard of the touch area size was set up.

The more the touch area is wide, the more the touch succeeding rate will be elevated. In this case, however, the information amount in the screen is restricted.

Such being the case, even if any touch mistake has occurred, in the case of less influence upon the plant, the touch area may be decreased comparatively.

The other way, for the operation of pump and valve, the touch area must be increased, and the space between the touch areas must be left.

The above mentioned measures will be useful to prevent erroneous operation.

Alarm Display:

The numbers of alarm windows are many in the nuclear power plant. Therefore, in the course of compaction of the main control board, the specification of the alarm display becomes an essential theme.

As described in the Stage 2 of the above mentioned operation verification, “Development and validation of prototype”, the following specifications of the alarm displaying were adopted. But, according to the results of validation test (questionnaires), we were unable to obtain sufficient evaluations from the results.

(1) The shared alarms per system were displayed in the applicable generated place on the large display panel used for the system graphic display. And the shared alarms were displayed on the large display panel with 3-level categorized color coordination (Red, yellow ad green) classified by importance of the alarm to be activated.

(2) The alarm screen in order of time can be displayed by requests on the operator console and shift supervisor console.

In this way, according to the development and validation of prototype, the large display panel was specified as a major device to recognize alarm. As a result, during the period shifting from the alarm recognition to the request of control/monitoring screen, the thinking power has been interrupted. Such being the case, as the countermeasure to be taken so as to improve the Alarm Display System, the special attention has been paid to easiness of the shifting from the alarm recognition to control/monitoring as follows:

(3) The exclusive alarm displaying CRT has been installed on the operator console.

(4) By touching the activated alarm on the exclusive alarm screen to be displaying the exclusive alarm CRT, the monitoring/operation screen to be provided for the activated alarm was displayed on the CRT.

(5) The interlock action to be confirmed at the activated alarm was checked automatically. Then the checking results will be displayed on the exclusive alarm displaying CRT screen together with the activated alarm.

(6) The alarms displayed on the large display panel changed the shared level depending on the importance of the alarm, thereby when the more critical/important alarm activated, the plant status can be confirmed by the

large display panel. (Refer to Fig. 3)

After improving the Alarm Display, and as a result of the verification (Stage 2 of the above mentioned operation verification) by the utility operating crews, it has been confirmed that:

- Recognition of alarm activating by means of the exclusive alarm displaying CRT and the large display panel,
- Easefulness of alarm confirmation process starting from the recognition of alarm activating to the confirmation of the plant status, the judgment of plant status and countermeasures to be taken, and
- Easefulness to detect the relating secondary failures which continuously occurred during taking the countermeasures.

In the verification process, it was simulated that the secondary failures occurred during taking the countermeasures, after the major event occurred.

Actually, in the course of the simulation, the time was measured, starting from the occurrence of the secondary failures until the operator may detect the secondary failures. Then, the measure results were compared with evaluation data obtained from the conventional-type main control board.
The actual evaluation result is shown in Fig.4.

According to the evaluation result, the detectable time of the relating secondary failures has been shortened successfully on the operators' time average in comparison with that of the conventional plant. Moreover, for the time distribution among inter-operators, it has been confirmed that the alarm system of the Advanced Main Control Console has narrow distribution in comparison with that of the conventional plant. Then it has been also confirmed that the detection time can be shortened successfully regardless of the plant operators' personal capabilities.

Integrated Evaluation:

Evaluation of Human Error Probability (HEP):

As a calculation method of the Evaluation of Human Error Probability (HEP), generally and widely utilized "NUREG/CR-1278 & 2254" were used.

As an object of the evaluation, it selected the scenario which human error might exert a great influence upon the safety of the plant (such as the checking of plant trip).

As the result of evaluation, the human error occurrence rate at the Advanced Main Control Console has decreased by 2/3 in comparison with that of the conventional-type main control panel by adopting an automatic checking function and monitoring operation integration display by utilizing a computer system. (Refer to Table 1)

Evaluation of Workload:

The physical workload has drastically improved compared with the conventional-type main control board by adopting the sit-down-operation method with Advanced Main Control Console.

In other words, conventionally available traveling distance for the plant operators working in the plant has become meaningless.

On the other hand, there is anxiety about the increase of mental workload.

Therefore, Mr. Card and others of XEROX Corp. in U.S.A. proposed to use the method of human information processing model.

Then by using the above-mentioned method, we have evaluated the mental workload in the operation monitoring process by using the Advanced Main Control Console.

According to the human information processing model, the operator was assigned as one of information systems, and then, the human information processing course was divided into “Consciousness”, “Recognition” and “Motion processing” respectively.

In this way, the applicable processing times were calculated and evaluated.

Fig. 6 shows the processing elements required for the carrying out the fundamental jobs successfully. Referring to Fig. 6, seeing from a crew’s task, a reaction of “when the operator heard an alarm sound, he looks around” may correspond with “Simple reaction”. In the course of a certain process, a process of “Select the operational target” may correspond with “Description verification”.

In this way, crews’ tasks are all able to classify into the fundamental job.

Therefore, by using this method, times during which the crews must actually use brains were calculated and evaluated.

As the results of the above mentioned evaluation, it has been cleared that the workload of the Advanced Main Control Console reduced by approximately 2/3 in comparison with that of the conventional-type main control board.

(Refer to Table 2)

Verification of Evaluated Operators:
As described above, according to Stage2, Execution of prototype development verification, the required operational sequence to be executed in the verification scenario are checked so as to make sure whether the operational sequence has been made practically or not.

As the result of checking, even by the one operator, the achievement of monitoring/operation item is practically 100%.
Then the operability of the Advanced Main Control Console was confirmed as the same as that of the conventional-type main control board.

Moreover, according to the results of questionnaires, we have obtained answers that more than 80% of plant operators have no problem against the applicable specifications (except alarm specification and trimming (fine-tune) operation).

In addition, for the alarm specification, it was confirmed at Stage3: Verification of an alarm system.
On the other hand, for the trimming operation, it was determined to verify by Stage4: Validation test of mock-up for the actual plant.

CONCLUSIONS

It is believed that the Advanced Main Control Console would be applicable successfully to the next generation Plant.

We will attempt achieving further improvement of operation reliability of the Advanced Main Control Console, as well as to reduce the facility cost.
In order to satisfy the above requirements, it is prerequisite to establish the standardized specification, as well as to standardize the software architecture.

Such being the case, we have set up the design guideline for the Advanced Main Control Console. Then according to Stage4: Validation test of mock-up for the actual plant, from the later half of 1998, the dynamic operator verification linked with a simulator is being executed, as well as operational know-how is being collected, and detailed standardization is being executed (Refer to Fig. 6).

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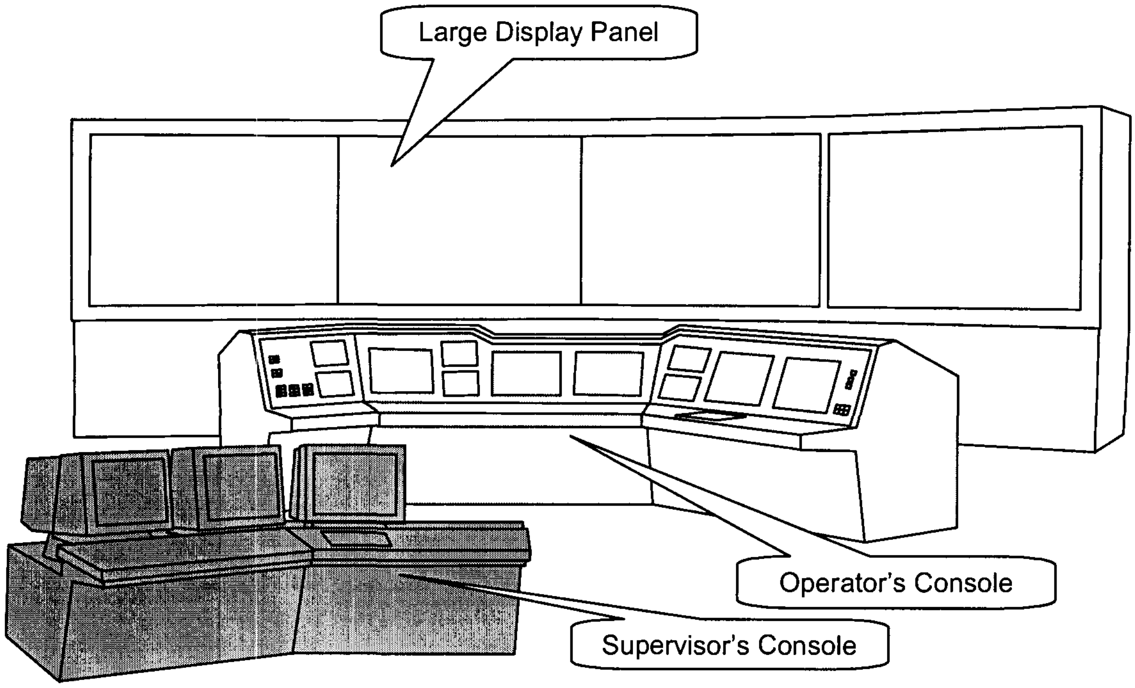


Fig. 1 Main Control Board Configuration

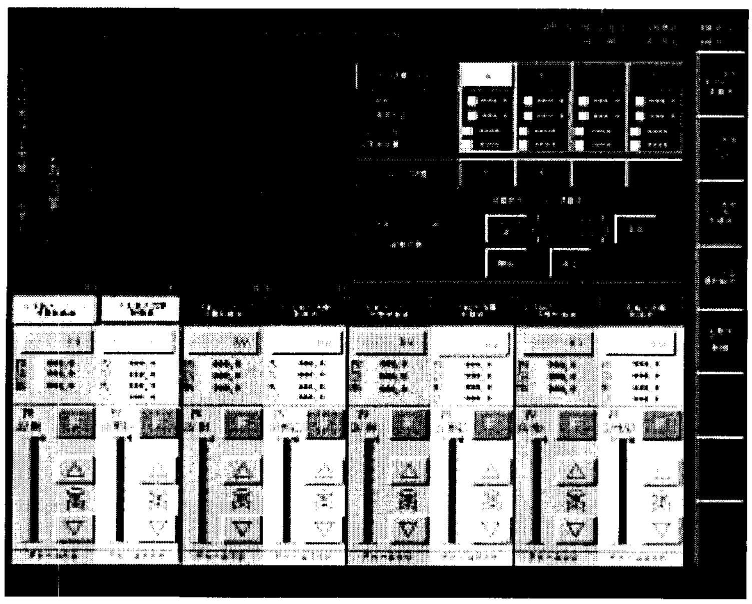


Fig. 2 Integrated Displays for Control & Monitoring

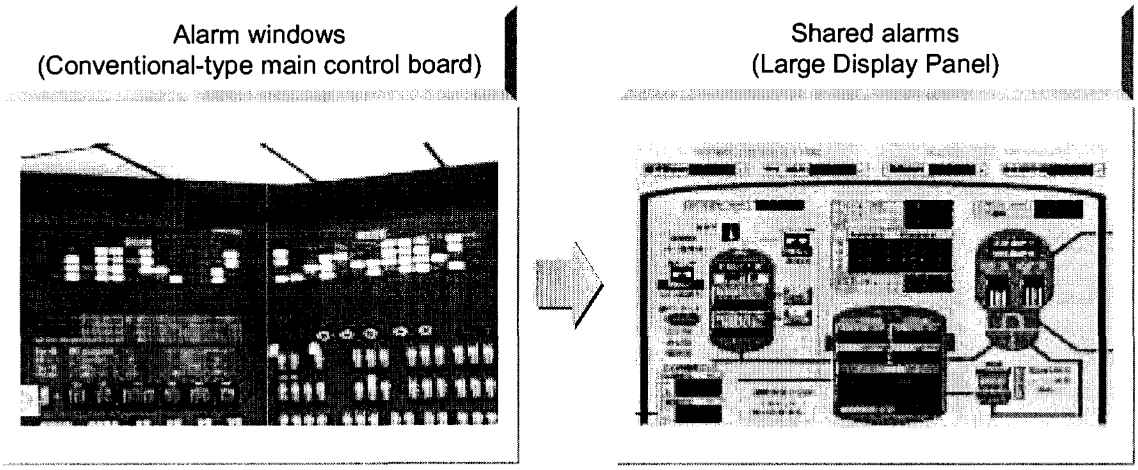
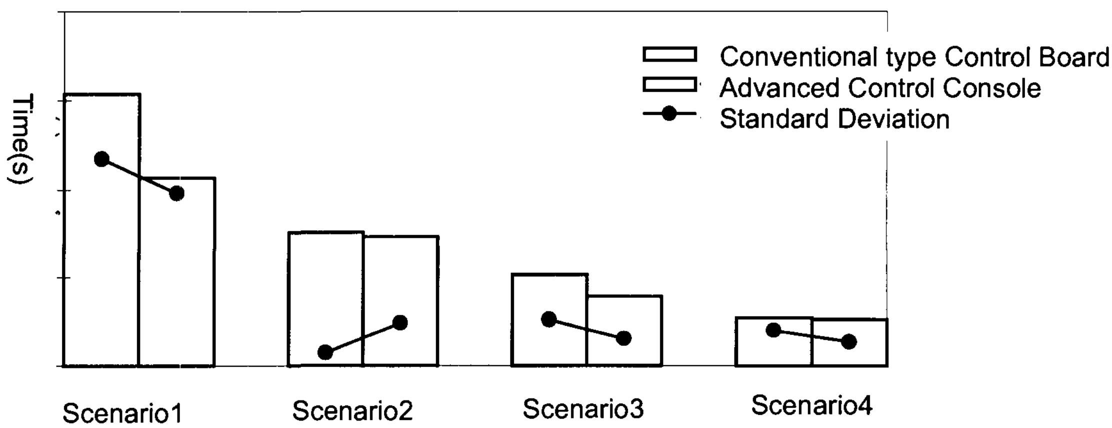


Fig. 3 Improvement of Alarm Displays



Scenario1: Steam Generator Tube Leak + Feed water control valve failure
Scenario2: Station Black Out + Charging Pump failure
Scenario3: Generator Load Rejection + Pressurized Splay Valve failure
Scenario4: Reactor Trip + Control Rod Stick

Fig. 4 Time to identify secondary failures

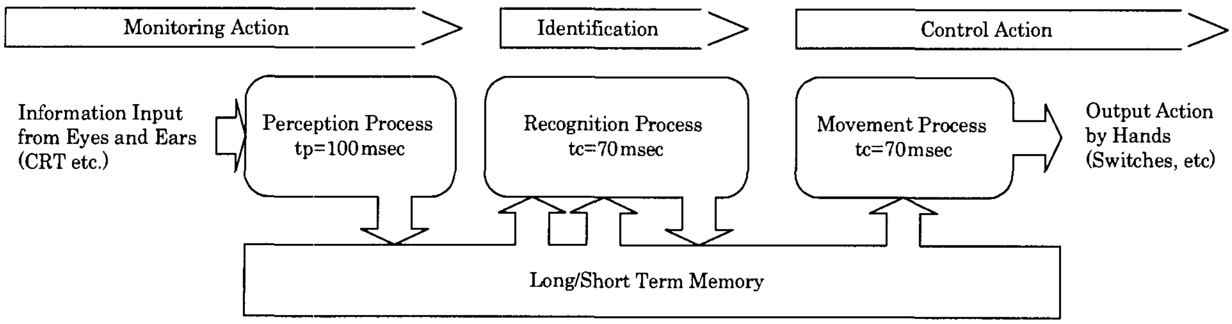


Fig. 6 @Human Information Processing Model

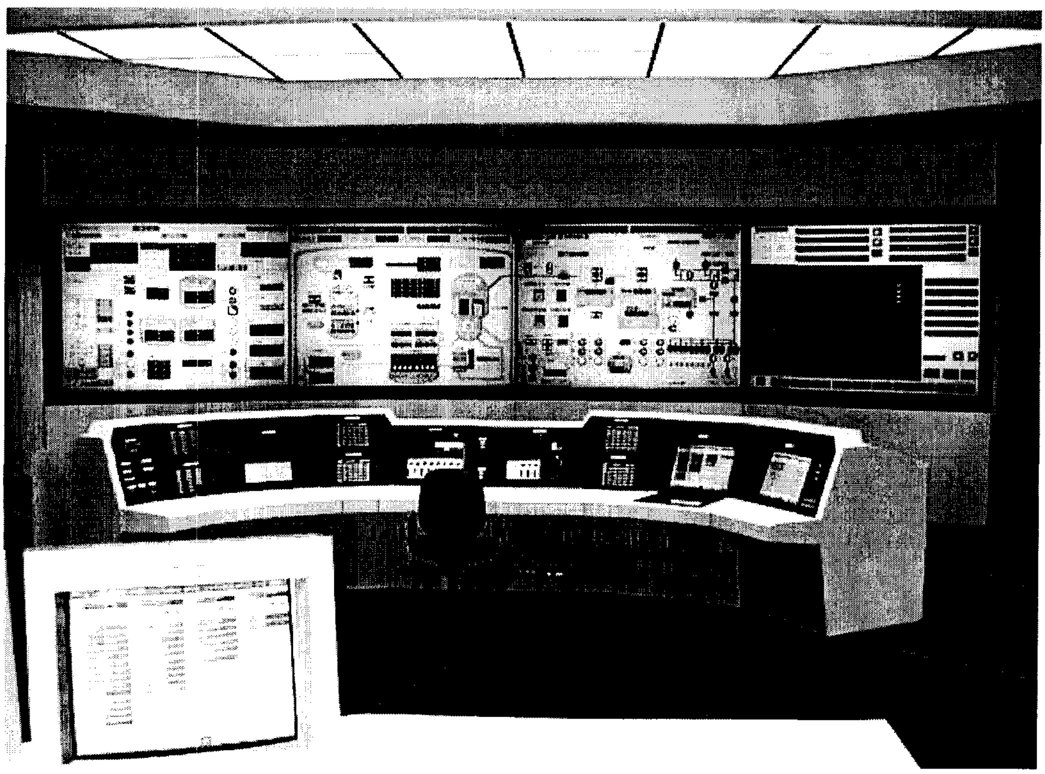


Fig. 6 Variation Test Facility of the Advanced Main Control Boards

Scenario		Result (Reduction)
Operation mode	Accident	56.5
	Normal Condition	30.5
Monitoring mode	Accident	17.6
Total		32.2

Table 1 Evaluation Results (Human Error Probability (THERP))

Sequence	Result (Reduction)
Trip	29
S.I.	46
B.O.	47

Table 2 Evaluation Results (Mental Work Load)