Study on Main Control Room and Human-system Interface of Generation III in China

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ABSTRACT

This paper focuses on the study on Main Control Room (MCR) and Human-System Interface (HSI) of Generation III in China. An intelligent HSI has been developed to enhance the safety and availability of Nuclear Power Plant (NPP) by improving operational reliability. The key elements of the proposed HSI such as Advanced Alarm System, State Oriented Procedures (SOP) , Large Display Panel (LDP), Computerized-base procedures…, that affects what information the operator sees or the system's response to a control input must be empirically evaluated to ensure that the new design does not compromise HSI effectiveness. Based on CPR1000's experience in China, this paper presents the approach used as well as the most relevant aspects of this kind of project for the next generation. This approach will be used in new Generation III nuclear power plant, and also used in modernizing I&C system in currently operative nuclear power plants, in addition to meeting safety requirements and the plant's operational requirements, to improve cost-effective plant and human performance and to reduce likelihood of human errors, to gain maximum benefit of the implemented technology and to increase the performance, resulting in improved plant safety, availability, reliability, and cost-effective operation. The proposed HSI has been validated and demonstrated using the CPR1000 simulator of National Key Laboratory. After sufficient validation, the characteristic design features of the proposed HSI will be reflected in the design of the main control room of the next generation reactors in China.

Key Words: Human System Interface, Advanced Control Room,Intelligent

1 INTRODUCTION

The nuclear power industry has been developing and improving reactor technology for more than five decades and is starting to build the next generation of nuclear power reactors to fill new orders. Several generations of reactors are commonly distinguished. Generation I reactors were developed in 1950-60s, and outside the UK none are still running today. Generation II reactors are typified by the present US and French fleets and most in operation elsewhere. So-called Generation III (and III+) are the advanced reactors discussed in this paper, though the distinction from Generation II is arbitrary. The first are in operation in Japan and others are under construction or ready to be ordered. Generation IV designs are still on the drawing board and will not be operational before 2020 at the earliest.

So-called third-generation reactors have:

- A standardized design for each type to expedite licensing, reduce capital cost and reduce construction time.
- A simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets.
- Higher availability and longer operating life – typically 60 years.

- Further reduced possibility of core melt accidents.
- Substantial grace period, so that following shutdown the plant requires no active intervention for (typically) 72 hours.
- Resistance to serious damage that would allow radiological release from an aircraft impact.
- Higher burn-up to use fuel more fully and efficiently and reduce the amount of waste.
- Greater use of burnable absorbers ('poisons') to extend fuel life.

In China, CGNPC has adapted the successful features of M310 reactors (French Generation II technology), to establish CPR1000 reactors (China Generation II+ technology), to R&D Generation III reactors(See Fig.1).

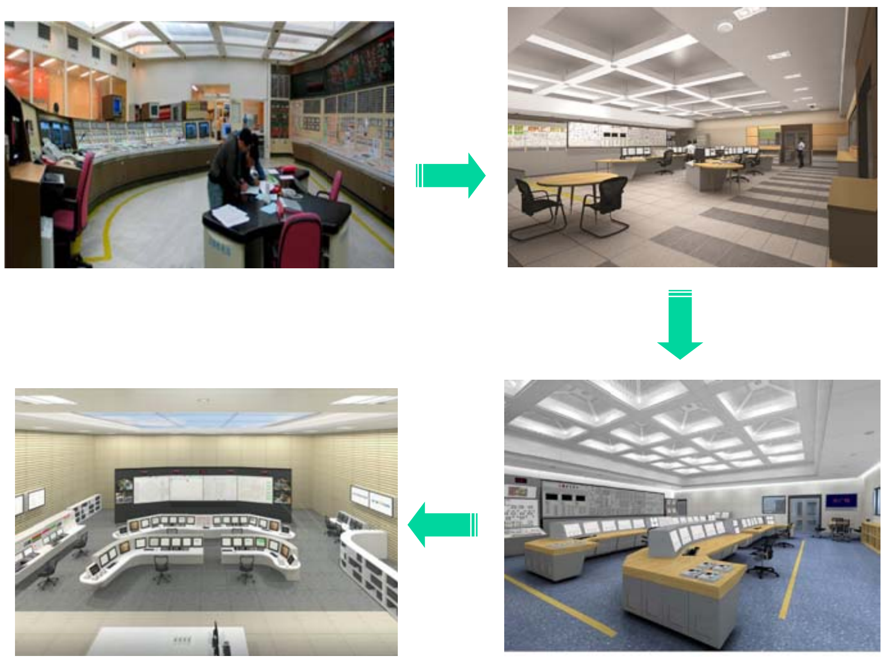

Figure 1. Evolution of Main Control Room in China

The MCR design has evolved since the original M310 plants such as LingAo 1&2. Comparing with LingAo 1&2, there are no change in the current assignment for the operation staff composed of: one Unit Supervisor (US),two operators: Reactor Operator (NI/OP1) and Secondary Operator (CI/OP2),one Safety Technical Adviser (STA),one Shift Supervisor (SS) who hold the STA role before he arrives in the main control room, local operators with empowered skills to perform the local operation requested by the NI/OP1, CI/OP2 or US, on call maintenance people. A common theme is that all these plants have computer control and an increasing degree of computer-generated "soft control" and seldom conventional "hard control" as designs have evolved. Changes made to the HIS affect the way that information is presented to personnel. For example, rather than being presented via individual, spatially dedicated instruments, the information may be presented via computer-based video display units (VDUs).Computer-based systems provide the opportunity to automate various cognitive functions, such as with computerized procedures, automatic diagnosis, advanced alarm processing system, etc. These changes in automation can impact the role of plant personnel, as well as significantly affect individual and team performance. Four important trends in the evolution of MCR are (1)increased automation, (2) the development of compact, computer-based work stations, and (3) the development of intelligent operator aids. (4)The human factors engineering and plant operating experiences were also integrated in these designs. In addition, human factors are incorporated in the design of control room layout and information presentation. However, there are some issues most frequently associated with MCR. They include (1) increase in the operator's cognitive workload associated with managing the interface, (2) difficulty navigating through and finding important information presented in visual display units (VDUs), (3) difficulty understanding how advanced systems work, (4) great shifts in operator workload in the event of a computer failure, and (5) loss of operator vigilance, pattern recognition ability, and skill proficiency. In this paper, an advanced HSI is proposed specifically for operators by addressing the issues associated with MCR. The design goals for the proposed HMI are to (1) reduce operators' physical/mental workload, (2) eliminate human errors that can affect plant safety and availability as much as possible, (3) design monitoring and control functions simply and consistently, and (4) assure the highest possible reliability of the control room.

2 CONFIGUARTUION OF HUMAN-SYSTEM INTERFACE

The use of the new digital I&C systems in the design of the new nuclear power plants, as well as the modernization of the existing ones, implies relevant changes in the control room and Human-system Interface design. Meanwhile, New I&C systems in the next generation provide new features that a ffect the control room operating concept, therefore a detailed analysis is required to take into consideratio n all the operating and human factor aspects.

The methodological approach of new control rooms must necessarily combine two fundamental aspects:

- Digital technologies introduce the opportunity for new functionality in the form of advanced displays and automated or soft controls. To fully benefit of the advantages provided by such I&C technology, specific developments of those products have to be avoided as far as possible. Moreover relying on proven mechanisms is advisable as it contributes to a stable and reliable system and might reduce long-term maintenance costs. Computer-based HSI technology is being integrated into plants as part of plant modernization programs leading to modifications to control rooms, remote shutdown facilities, and local panels.
- Developing guidance for specifying and designing control rooms, remote shut-down station, HSIs, etc. The guidance is of four types. The first is planning guidance to develop its plant-specific control room digitization operating concepts, human factors program plans, etc. The second is process guidance for general HSI design and integration, human factors engineering analyses, verification and validation, soft control processes, etc. The third is detailed human factors engineering guidance for control room and HSI technical areas. The fourth is guidance for special topics related to operations and maintenance including training and simulation and safety monitoring and control guidance.

The Plant computer Information and Control System (PICS) architecture of NPP units in China, organization and features should be consistent with the shift-team organization and tasks while minimizing the operating constraints. The PICS composition follows these principles:

- one Computerized Operating Work Station (OWS) for two operators (NI/CI) in MCR,
- one OWS for STA and one OWS for SS in MCR,
- two compact OWS for two operators(NI/CI) and one shift leader without OWS in Remote

Shutdown Station (RSS),

- the right to send commands to the process depends on the user role: only the operators are allowed to send orders.

The key features of the unit for the Generation III MCR are as follows:

2.1 Main Control Area and Operating Means

Main Control Area is consistent with the need for improved human factors in the MCR, which is an essential factor for improving the task performance of the operators:

a) 4 sets of OWS are arranged in MCR. Each is OWS for NI operation (Reactor operator),OWS for CI operation (Secondary system operator), OWS for US and SE. Because each OWS becomes OWS for backup by failure of OWS, 4 OWSs have same function,

b) ECP is installed between with OWS for NI and OWS for CI,

c) SVDU as control means of safety classified path.

Four operating configurations need to be taken into account:

- Standard configuration (no loss of HSI functions)

The operation of the plant is performed from the Main Control Mean(MCM) whatever the plant state is, provided that the technical and operating criteria for MCM are met. In this mode, the secondary control means are not allowed to send orders to the process.

- First degraded operating configuration (loss of OWS)

The loss of the MCM is defined by a set of criteria that are both technical criteria and operation criteria. The criteria based on the operation needs are mainly defined by determining the minimum configuration of the MCM required in order to using Emergency operating procedures.

- Second degraded operating configuration (loss of MCR)

The main control room is considered as lost: the operation of the plant is transferred to the RSS where the plant is brought and maintained in the safe shutdown conditions. Before leaving the MCR, the shift team performs preliminary actions like tripping the reactor. Once arrived in the RSS, the MCR control means (MCM, ACP and ECP) are isolated from the process so that they are not allowed to send orders.

- Third degraded operating configuration (loss of all digital DCS)

The all digitalized DCS including HSI related processors is considered as lost in case of CCF of computer software, so the operation of the plant is transferred to the ACP. The MCM and the RSS are not allowed to send orders to the process.

Auxiliary Control Panel (ACP) is designed to control the essential functions required for plant safe shutdown should controls on the work stations become inoperative. The control devices on this panel adopt hardwired logic for diversity purposes in order to avoid a common mode failure with the work stations.

And the digital technology has been introduced to the Advanced Control Room (ACR) called the computerized Human Machine Interface. The control means of ACR should be sufficiently reliable that it will never be triggered a complete loss or never be stopped for maintenance purposes, and should always support the demonstration of the safety classified path. The Plant Control and Monitoring System and Operation system utilizing the safety DCS digital platform such as Safety-VDU for separating the control means to safety devices. When an operator selects safety components in Non-safety VDU, the soft operation switch pops up on the Safety VDU. The control means of Backup should be sufficiently reliable that it will never be triggered a complete loss or never be stopped for maintenance purposes, and should always support the demonstration of the safety classified path. Due to the loss part function of normal control and monitoring means which are named Main Control Means (MCM) in MCR, the study analyzes the possible degraded operating configuration of different control means and focuses on the application.

Based on the operation and design principles of the CPR1000 NPP, three major developments on the proposed HSI that are:

- Main Control Means of safety classified path
- Backup of Main Control Means of safety classified path
- Human factor design such as Large display Panel, Environmental Design…etc.

2.2 Large Display Panel

Large Display Panel is also called Plant Overview Panel which is an equipment presenting the overall plant status in a large size arrangement, and is useable in all plant states as long as the PICS is available:

- for the co-ordination and information sharing among the operating team,
- to allow to fast become aware of the unit status, to be a common reference for all control room staff or any people present in the MCR,
- to be treated as a particular Operating Workplace disposing of large screens and configured in "supervising mode"

It is implemented in the form of four large panels in the next generation. The images presented on the LDP could be chosen freely by the operators among all the images available from the PICS. A set of dedicated displays will be designed for the LDP. They shall present the information suitable to get a quick and reliable overview of the plant status (NI/CI/electrical plant information, trend of significant analogue values, main safety and availability parameters, main components status...). in addition to the information already available on the OWS. Such displays should be as simple as possible without unnecessary information in order to facilitate their use by both the operators (quick analyses of the situation) and by other staff entering in the MCR.

2.3 MCR Environmental Design

The purpose of environment design for the MCR is to create a pleasant and comfortable working environment through applying the aesthetic design concept and HFE principle. The HFE team performed the HFE evaluation for the integrated MCR environment design including interior, lighting and color design. As a result, it should be noted that the proposed MCR environment design meets the HFE criteria and no discrepancies are found. The advantages and characteristics are addressed as follows:

- Minimization of the human stress and fatigue through the pleasant and comfortable working space by applying human-centered interior concept,
- Application of working space requirements and Chinese anthropometry data to the MCR layout design including OWS, LDP, ACP and furniture to minimize the operators' movement and human error that may occur during the plant operation,
- Prevention of the physical and psychological stress through the user-friendly lighting design that provides optimum illumination level adjusted depending on each task area,
- Use of color and lighting to create a cheerful atmosphere without introducing glare and brightness to a degree that causes eye fatigue.

2.4 Remote Shut Down Station

The function of the RSS is to cope with the unavailability of the main control room, without any additional failure or accident. The RSS provides the means, to bring into and to maintain the plant in safe shutdown conditions. This requirement results in the implementation of the functions which are strictly needed for this purpose, assuming that this condition is not indefinite and that field actions can be carried out on operator's request.

3.10. Technical Support Centre

As an emergency response facility, a Technical Support Centre (TSC) providing information and communication means is foreseen on site. It can be used in case of accidents by a support team consulting the operating staff.

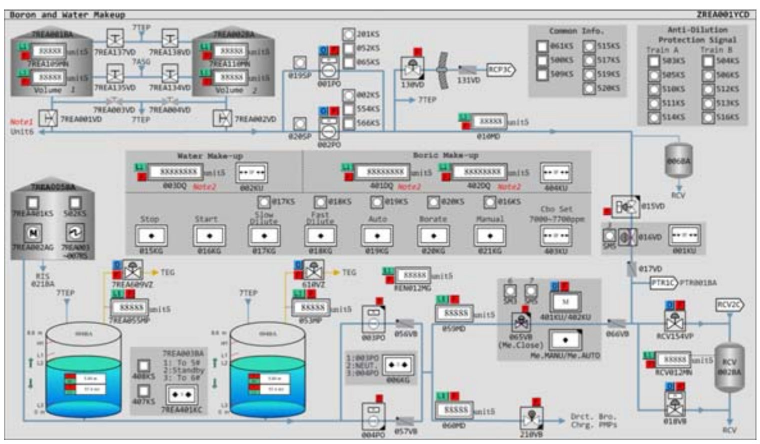

Figure 2. 3-D symbol Display of Plant Status Monitoring and Control

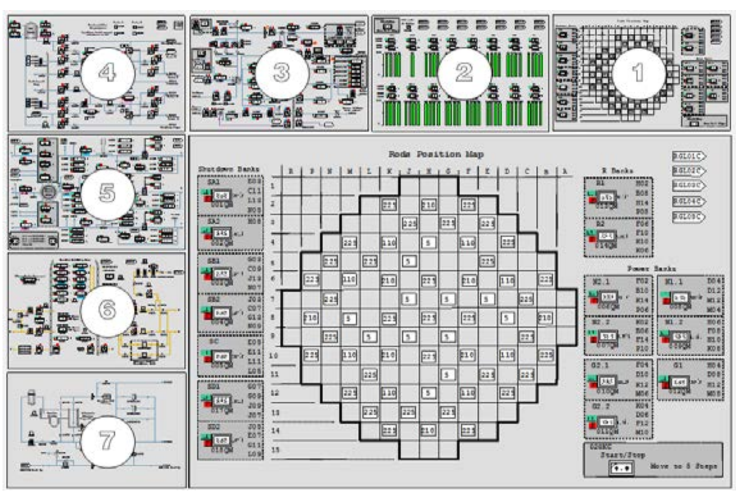

Figure 3. PIP Functions of System Information

Figure 4. Dynamic Alarm Prioritization Management

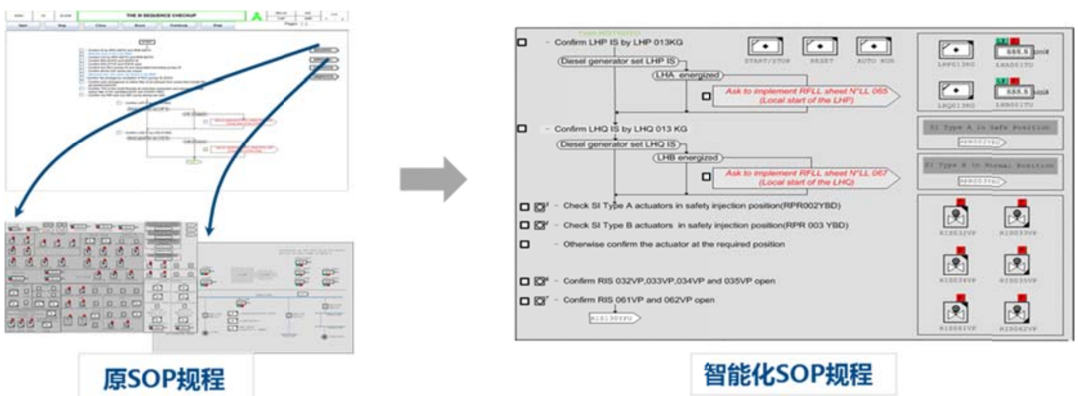

Figure 5. Integrated Automation Functions of SOP procedure

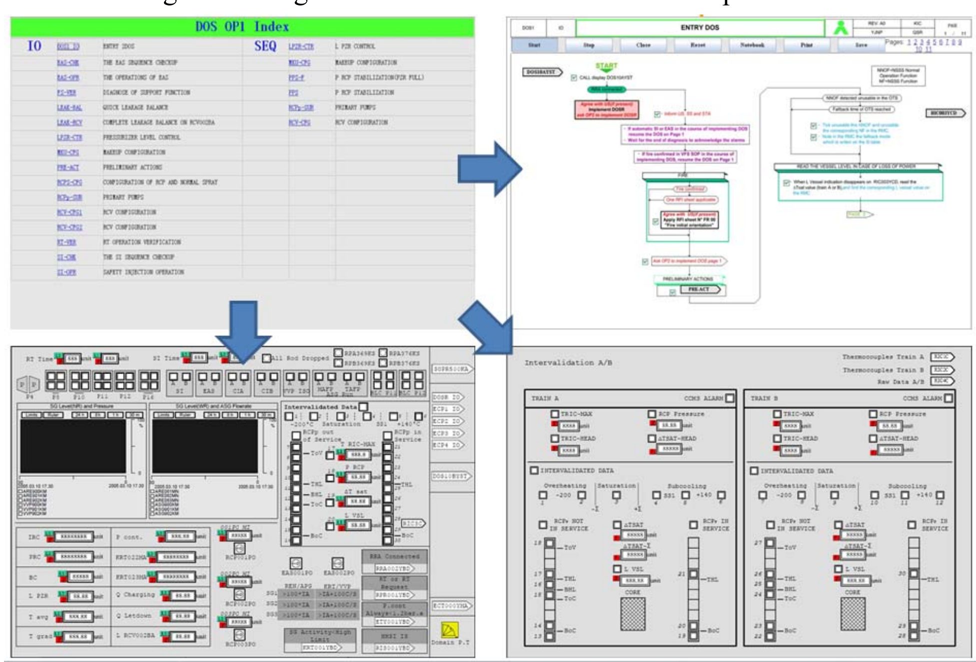

Figure 6. Automated Navigation Multi-screen Display of SOP Procedure

3 DEVELOPMENT STRATEGIES OF INTELLIGENT MCR AND HSI

3.1 Centralized Process Control

The MCR is the place for process control and supervision in all plant situations. In addition, it has to provide the means for communication to outside. At the same time, it is the center to initiate the maintenance of process-related equipment. The key information is presented in various formats including symbol, text and graph, and color coding is consistently used to indicate the degree of alarm impact, the operating status of equipment/components, and the deviations from normal ranges of quantitative variables. Some Intelligent elements such as 3-D symbol(See Fig.2), dynamic text, Picture in Picture(PIP) (See Fig.3),Mouse automatic positioning, plant situation auto-diagnosis…, will be developed in the HSI for next generation in China.

3.2 Advanced Alarm System

There have been several proposed evolutionary alarm designs that perform rudimentary prioritization, improved filtering, consolidation, and mode dependence in the Generation III. Connecting the alarm system with some kind of smart alarm sheets can be helpful. In addition to the normally thought of prioritization, filtering, and suppression, digital capabilities would allow alarms to be directed appropriately and with different priorities. Multi-threshold inhibitions, the cause inhibits its consequences, inhibition by synthetic alarm, inhibition by padlocked components should be considered. For example, non-important equipment fault alarms that are informative for the system engineer or maintenance person could be routed to them rather than going into an alarm for the operator.

Connecting the alarm system with a kind of alarm sheets(alarm operation procedure) can be helpful for operators. In addition to the normally thought of prioritization, filtering, and suppression, digital capabilities would allow alarms to be directed appropriately and with different priorities (See Fig.4). Multi-threshold inhibitions, the cause inhibits its consequences, inhibition by synthetic alarm, inhibition by padlocked components should be considered. For example, non-important equipment fault alarms that are informative for the system engineer or maintenance person could be routed to them rather than going into an alarm for the operator.

3.3 State Oriented Procedures

After TMI accident, which brought up the inadequacy of event-based approach for the management of complex situations and called for a significant evolution of emergency operating procedures, a state-oriented approach was worked out based on the physical state of the plant for Emergency Operating procedures. State-oriented approach does not require the operator to identify the events that cause the accident. The operator diagnoses the physical state of the plant from a limited set of values of physical parameters, without having to find out the sequence of events that led to this physical state. Compare to CPR1000,in the proposed HSI, emergency Operating procedures were automated to support the operator in coping with some emergency state, some automation functions of qualitative judgment and checkbox automatic performance were implemented in the FANGCHENGGANG NPP project in China(See Fig.5). The plant parameters related to the current instruction are dynamically displayed on the multi-screen if the operator clicks the instruction (See Fig.6).Such approach corresponds to reduction of the operator's decision-making time in detection, observation, identification, and interpretation.

4 HUMAN FACTOR ENGINEERING

The further enforcement of the operation principles shall therefore be performed according to the Human Factor Engineering standards retained as reference, which are mainly the IEC964 completed by the IEC 61839,IEC 1771 and IEC 1772,IEEE STD 1023-2004,NUREG 0800/0700/0711 ,etc. These general principles regarding Human Factors concerns comply with the HAF 102 that is part of the Chinese safety regulation. The following two items are chosen as the objectives of the proposed HSI evalution:1)Validate the performance of the intelligent elements for the proposed HSI including PIP, alarm filtering and prioritization,etc.2)Observe the operator's time response for completing required actions during an emergency condition to evaluate the effects of development. The evaluation of the proposed HSI was performed using the real-time simulator for National Key Laboratory with a systematic measurement-based approach (See Fig.7). In case of an emergency condition (for example LOCA), it is to compare time response data obtained from three groups of operators. Each group used the CPR1000 HSI and the proposed HSI to response to simulated accident. The purpose of the evaluation is to determine whether or not the operator using the HSI were advantageous in stabilizing plant conditions as measured by time in comparison with those using the CPR1000's. Human factors related problems should be considered appropriately from the early design phase to the development phase of the HSI. This means that the HSI should be designed and evaluated through the whole design phase in order to maximize the performance of operators' primary tasks (process monitoring, decision-making and process control), and to minimize their errors and workload. For this purpose, HSI designers have been faced with the problems of (1) designing an HSI to address human factors issues satisfactorily, and (2) evaluating the efficacy of a designed HSI.

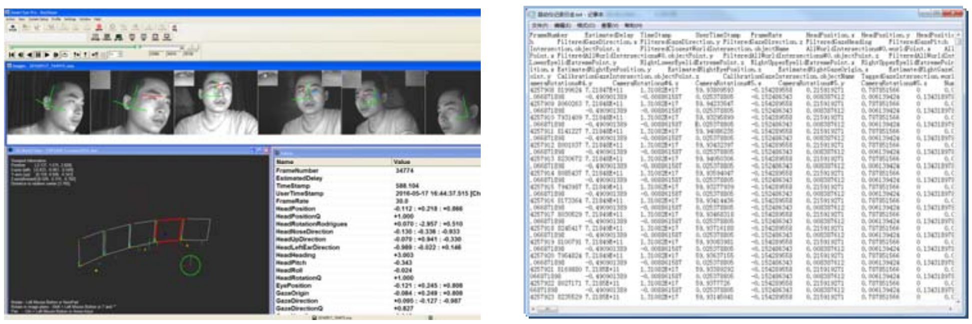

Figure 7. Test for CPR1000 and Generation III HSI

Test Results

The advanced HSI for next generation nuclear power plants has been developed and demonstrated:1. All operating information is displayed as much as possible to help operators' comprehension, considering their Chinese culture. The configuration of the work stations and the layout of the CRT displays were designed by focusing attention on the importance of the operators' role for NPPs.2. Alarm hierarchy was established on the basis of the physical and functional importance of alarms to show the propagation of alarm impact from equipment level to plant functional level. In addition, the normally thought of prioritization, filtering, and suppression, are logically processed from generation to presentation.3.The operating procedures are electronically integrated with requisite plant information, checkbox automatic performance and are traced with the interaction of the operator. The proposed HSI has been evaluated statically to review whether it is properly designed to deal with human factors issues reasonably. Based on the results of the static evaluation, the irrelevant designs have been modified to meet the related human factors guidelines.

The Large Break Loss of Coolant Accident (LB-LOCA) was chosen as the test event because it is safety significant and involves intensive HSI among the operating crews and the plant. The test results on LOCA emergency states are given in Table I. As shown in the table, execution time were reduced by ~46% on the average, number of displays were reduced by ~48%, number of procedures were reduced by ~44.44% ,searching parameters average time were reduced by ~69% on the average by the Generation III. The major cause of reduction is the development of intelligent element and integrated automation functions of procedure for Generation III. In Table II, the third and forth column show the response time of CPR1000 and Generation III HSI, respectively. As shown in the table, response time were reduced by

~46% on the average. Judging from these results, it can be concluded that automation is effective enough to reduce response time and the operator's physical burden in the operation task. In conclusion, a key advantage of the proposed HSI would be its capability to support intelligent decision making by the operator for the whole spectrum of reactor operation, especially in interpretation and planning in non-routine situations such as handling plant disturbances.

Table I. Test Results table: Execution Time

		CPR1000	G III	Rate
Execution time (min)	1	16	9	43.75%
	2	15	8	46.67%
	3	15	8	46.67%
Number of Displays		25	13	48%
Number of Procedures		9	5	44.44%
Searching parameters average time(s)	1	7	2	71.43%
	2	6	2	66.67%
	3	6	2	66.67%

Table II. Test Results table: Response Time

Operator Group Number	Screen	CPR1000 Response time(s)	G III Response time(s)	Rate
1	1	99.6584233	47.6582143	52.18%
	2	55.6812354	38.6548251	30.58%
	3	504.8412821	350.6841354	30.54%
	4	310.7592135	104.8423651	66.26%
	Total	970.9401543	541.8395399	44.19%
2	1	89.2455096	46.5976051	47.79%
	2	30.7827102	22.4174454	27.18%
	3	525.4898912	329.5946086	37.28%
	4	270.5281933	83.9483697	68.97%
	Total	916.0463043	482.5580288	47.32%
3	1	77.5681314	37.6542315	51.46%
	2	34.8524612	22.6852346	34.91%
	3	480.5684321	338.5681435	29.55%
	4	320.6584312	88.9652841	72.26%
	Total	913.6474559	487.8728937	46.60%
Searching time	Total	1168.417902	363.0684647	68.93%
Operating time	Total	2800.633915	1512.270462	46.00%

5 CONCLUSIONS

The Generation III MCR design is based upon the CPR1000 MCR with further upgrades to meet safety requirements and the plant's operational requirements with respect to the key design goals discussed above. An intelligent HSI has been developed to enhance the safety and availability of a nuclear power plant (NPP) by improving operational reliability. The proposed HSI has been validated and demonstrated using the real-time simulator of National Key Laboratory. After sufficient validation, the characteristic design features of the proposed HSI will be reflected in the design of the main control room of the Next Generation Reactor in China.

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