行政院原子能委員會
委託研究計畫研究報告

人因系統介面效能評估技術之研究

計畫編號：942001INER022
受委託機關（構）：清華大學
計畫主持人：黃雪玲
報告日期：94 年 11 月 15 日

中文摘要

本研究，針對台灣第四核能發電廠之先進化控制室內的自動化警報重置系統適用性進行評估。其自動化警報重置系統，特性包含依警報危急水準動態排序之及快速重置已解除之警報。本實驗分為二階段，分別用以量測專業與新手操作人員於自動化及手動重置系統之操作時間、情境知覺、工作負荷及客觀評量等效能。所有受試者於警報模擬器上，依序完成本實驗所選採之棄載程序。最後，實驗結果顯示，相較於手動重置系統之操作，受試者使用自動化重置系統可縮短操作時間，新手操作者之情境知覺亦相對提高。可知，自動化重置系統可有效應用於棄載程序。然而，為了確保核能第四發電廠之操作安全，自動化重置系統於其它程序書、特別操作要求或突發性事故之適用性，仍需逐一驗証之。

關鍵字：警報系統、核能發電廠、模擬系統

Abstract

This study evaluates the practicability of automatic reset alarm system in Fourth Nuclear Power Plant (FNPP) of Taiwan. The features of auto-reset alarm system include dynamic prioritization of all alarm signals and fast system reset. Two experiments were conducted to evaluate the effect of automatic/manual reset on operating time, SA (situational awareness) measure, TLX (task load index), and subjective ratings. All participants, including Experts and Novices, took part in the experiment on the alarm system simulator with Load Rejection procedure. The experimental results imply that the auto-reset alarm system may be applied in an advanced control room under Load Rejection procedure, because with the auto-reset alarm system, all participants' operation time were reduced as well as Novice's SA were raised up. However, to ensure operating safety in FNPP, the effects of the auto-reset alarm system in other procedures/special situations still need to be tested in the near future.

Keywords: Alarm system; Nuclear power plant; Simulation system

Contents

Figure captions

Table captions

1. Introduction

As more advanced technology and automation are introduced into power plants, it’s harder for the operator to know what’s going on inside the big black box. Operators rely on controls and displays to monitor the plant during normal and steady periods. When things go wrong, the use of alarm is an important strategy to find out which part of the system is causing the problem, and more importantly, to maintain the plant in a safe condition. Figure 1 is an abstract view, as envisioned in this research, of the relationship of plant, alarm system, and the operator. Sensors gather attributes of the system of the plant, and the gathered data are then processed. If criteria for alarm actuation are met, alarm will be sent to Alarm Human-System Interface (HSI). Operators perceive and manipulate alarms through Alarm HSI and take necessary actions through Plant HSI to deal with the abnormal conditions. The dotted area represents the macro scope of this research, that is, the interaction of Alarm HSI, Plant HSI and operators.

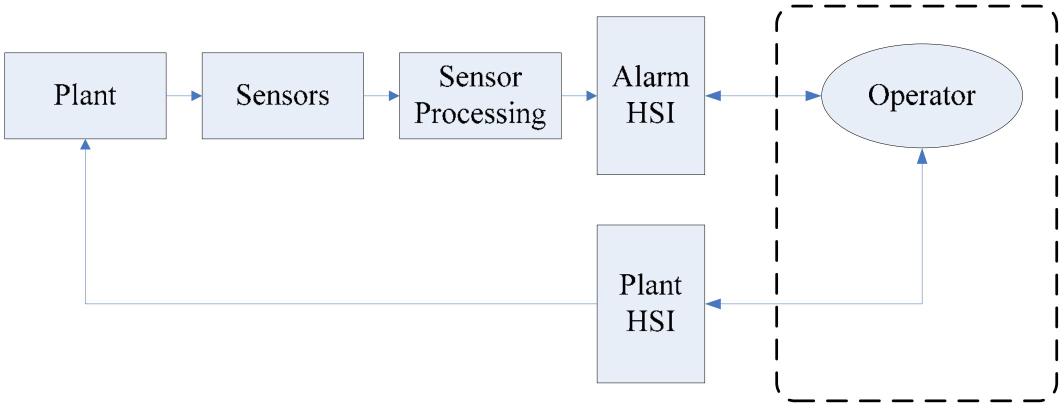


Fig. 1. An abstract view of plant, alarm, and operator

Traditional alarms are spatially dedicated alarms. Each alarm occupies a physical position in space and is directly accessible to the operator. In digitalized systems, alarms can also be shown in mimics or in a list window. As the complexity and the scale of the system grow, the sheer number of alarms has become overwhelming to the operator. The design of alarm system must take human capability and operator behavior into consideration.

The interaction of the operator and the alarm system can be examined with Alarm Initiated Activities (AIA) framework (Stanton, 1994). Initially, the onset of an alarm is perceived, and the operator accepts the alarm. After reading the alarm message, the operator analyzes current conditions and decides what to do next. The operator might have to take corrective actions or further investigation. To grasp how things are going after correction, continuous monitoring might be necessary.

It’s convenient to use AIA as a reference frame to consider possible directions for alarm system design. For example, as in an experimental research (O'Hara et al., 2000), alarm processing, availability, and visualization were studied. In terms of AIA framework, alarm processing and availability reduce the number of alarms that the operator has to handle. Innovative display and visualization techniques also make better the observability of alarms. However, the mechanism of alarm reset is not considered in the previous research.

Alarm reset mechanisms considered in this research are automatic reset and manual reset. With automatic reset design, returned-to-normal alarms are automatically reset to an unalarmed state. With manual reset design, such alarms must be reset manually. Literature on this topic is very few, if any. However, U.S. Nuclear Regulatory Commission’s Human-System Interface Design Review Guide (O'Hara et al., 2002, p. 289) has proposed recommendations of the design of reset functions, as quoted as follows:

> “4.3.4-2 Appropriate Use of Manual Reset
>
> A manual reset sequence should be used where it is important to explicitly inform users of a cleared condition that had once been deviant.
>
> *Additional Information*: An automatic reset sequence should not be used in this situation.6105
>
> 4.3.4-3 Appropriate Use of Automatic Reset

> An automatic reset sequence should be available where users have to respond to numerous alarms or where it is essential to quickly reset the system.
>
> *Additional Information*: A manual reset sequence should not be used in high-workload situations in which the time and attention required to reset the alarms may detract from other, more-critical tasks.6105"

There are some open questions regarding the above quotation. Will the use of automatic reset mask the operator's comprehension and prediction to the plant condition because the operator may not notice when the alarm are reset? Additionally, the Fourth Nuclear Power Plant (FNPP) in Taiwan is going to use automatic reset alarm system in operating control room. Besides the above-mentioned question, the reality situations/limitations of FNPP should also be considered; for example, the majority operators in FNPP are coming from other NPPs in Taiwan. All of them have operating experiences in traditional reset system more than 10 years, and this is the first time to apply the automatic reset alarm system in FNPP. The effects of the designed auto-reset alarm system and operator's operating experiences in FNPP need to be tested. This research will use experimental methodology to approach these questions. The aim of this study is to evaluate the practicability of automatic reset alarm system of FNPP in Taiwan for ensuring the operating safety.

2. Background

Operators of the modern nuclear power plants (NPPs) play the roles of supervisory controllers. To form the basis of this research and further discussion, previous researches on supervisory controller are reviewed in this section. Then we move on to the other part of this research – the alarm design. Alarm design involves many issues, such as sensor signals, alarm processing, alarm automations, and alarm representations. All of these topics are equally important and of great research value. However, this research focuses on the topic of alarm reset automation. Relevant researches on automation will be reviewed in this section.

2.1 Supervisory controller

With the advance of information technology, the operation of such complex systems as NPPs is accomplished through a human-system interface between the operator and the plant. Human operators no longer play the role of direct controllers, but of supervisory controllers instead. Although this intermediary relieves some burden of its human partner, it also puts new loading on operator’s perceptive and cognitive systems during the performance of a task.

To comprehend the interaction between the human operator and the alarm system, two models are chosen to be our basis. The first one is human information processing model (Wickens & Hollands, 2000) which represents the information processing as a series of stages. Almost every stage requires attention resource, so the resource is divided among them. Some stage might consume too much the attention resource such that other stages could suffer from poor performance. In addition, there are three kinds of storage in this model: short-term sensory storage, working memory, and long-term memory. The processing could start from a signal of the system or spontaneously from any stage of the model.

Based upon this model, there are several ways to alleviate the burden on the attention resource. In designing an alarm system, alarm representations affect how the alarm signals are sensed and perceived by human. The alarm signals come in as auditory or visual signals, which utilize different characteristics of our sensory organs (Rauterberg, 1998). Alarm processing (such as nuisance alarm analysis, first-out alarm analysis, and prioritization) could significantly reduce the number of signals for human to choose from. When the processing of the cognitive stage or the perception stage ends up with a decision to take actions, the alarm can automatically retrieve the response procedures relevant to the alarms.

Another model is Skill-Rule-Knowledge (SRK) model (Rasmussen, 1983). In this model, three categories of behaviors are identified. Skill-based behaviors are highly habitual ones, while rule-based behaviors are driven by explicit rules. Knowledge-based behaviors take high level thinking such as evaluation of situation, planning, and decision making.

As with the first model, several alarm human-system interface enhancement can be inspired by this model, such as automatic response procedure retrieval for rule-based behavior, or the design of alarm processing to reduce the number of input signals. In knowledge-based behaviors, expert systems can be derived to aid the situation assessment and decision making.

In addition to the aforementioned relevance to other aspects of an alarm system, these two models provide ways to think about alarm reset mechanisms, which are described as follows, respectively.

- Human information processing model: With automatic alarm reset, inputs to perception are reduced and automatically handled, and there isn't much need to execute any response plan. With manual alarm reset, however, each alarm has to be handled individually. These two alarm reset mechanisms are like two sides of the balance of attention resources. Too much on any one side would strike the balance status.
- SRK model: The adjective "automatic" in this context is a word full of meanings. To a minimal level, it could mean merely the function of automatic reset of an alarm. But it could also encompass a wide range of functions, such as checking the readings of other relevant systems, activation of consequential alarms, or

invoking necessary operations after the alarm reset. These “automatic” functions could be of rule-level or knowledge-level, which require more sophisticated system to support. In this research, automatic reset bears minimal meanings. Function-rich automation of alarm reset will be considered in future studies.

2.2 Automation

Automation has been studied in many literatures due to its great potential and pitfalls. Automation provides augmentation and enabling functions to human operators, and economics to the organizations; it could also incur costs, such as increased implicit complexity lowered arousal, distrust, and unfamiliarity (Sheridan 2002). The automation in question of this research is the automatic alarm reset. The alarm reset function places an alarm in an unalarmed state after the alarm conditions no longer exist. The automation reset of an alarm will take place for unacknowledged returned-to-normal alarms. Figure 2 is the state diagram of an alarm, where the automation reset is circled out by dash lines. Automatic alarm reset has the benefit of reducing the workload of the operator by reducing the number of alarm the operators have to handle. This is especially true during plant upsets when the operator would have to confront with alarm avalanche and escalated mental pressure. However, automatic alarm reset also has bad effects. If a returned-to-normal alarm is reset automatically, the operator may not be aware of the fact that such alarm has ever occurred, which may affect the overall evaluation of the plant status. Since alarms are very crucial for the understanding of the status of the plant, it’s very important to evaluate the effect of automatic alarm reset.

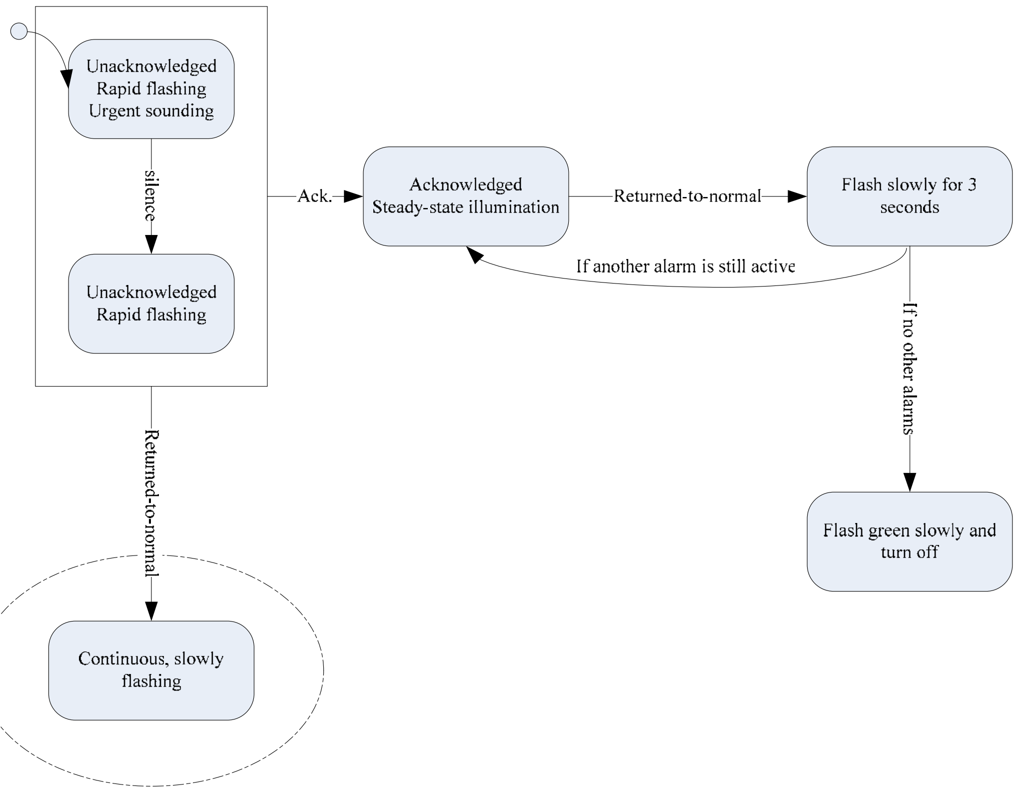


Fig. 2. The state diagram of an alarm

3. Alarm system simulator

The design goal for the alarm system simulator in FNPP is to evaluate the operation performance when using auto-reset alarm system. The simulation system from a useful platform may provide a convenient tool for operator training and safety analysis and can be an education tool to understand the design and operational characteristics. Also, there are more and more studies in the nuclear filed based on dynamic simulation/simulation system (e.g., Miller (1983), Huang and Hwang (2003a; 2003b), Shi et al. (2004), Hari et al. (2005), and so on). The alarm system simulator in this study includes two parts, PCTRAN system and alarm processing, that are connected to each other by Ethernet (As shown in Figure 3). Both PCTRAN system and alarm processing were developed by following the principles of FNPP and verified by related managers and operators who have operating experience more than 40 years on NPP in Taiwan. This section is divided into the following parts: PCTRAN system and alarm processing.

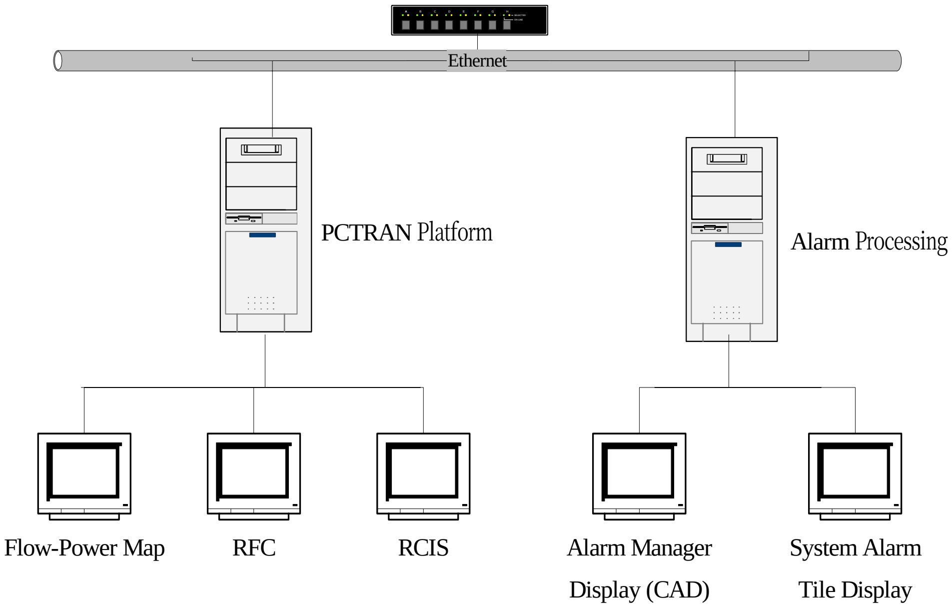


Fig. 3. The architecture of HFE test platform

3.1 PCTRAN system

The PCTRAN system is released by Micro Simulation Technology (MST), which is a transient and accident simulator for the reactor system. The PCTRAN system is also a simplified system, and fits the minimum requirements for the Human Factors Engineering Verification and Validation (HFE V&V). The PCTRAN was programmed as a simulator of the reactor system for training operators in FNPP.

The PCTRAN system includes Re-circulation Flow Controller System (RFC), Rod Control Information System (RCIS), and Flow-Power Map. The running status for each of these systems is presented on three Video Display Units (VDUs) respectively. The VDUs can provide the functions of directly monitoring to operators (e.g., allowing operators to withdraw/insert control rods on VDU of RCIS).

All control rods in the reactor system can be selected by individual, defined sequence, or groupings in RCIS. The VDU of RCIS also offers varying control modes, STEP, NOTCH, and CONT (continue) mode. Operators may select one of control modes and then click the withdraw/insert button to handle the selected control rods. In STEP mode, the selected rods are moved one notch as clicking the withdraw/insert button once; the selected rods are moved four notches if use NOTCH mode. Unlike STEP and NOTCH modes, the selected rods in CONT mode would keep on moving while pushing on the withdraw/insert button and once push off the buttons, it would stop immediately.

The VDU of RFC provides the functions of monitoring on 10 RIPs (Reactor Internal Pump) of the reactor system. Operator may manipulate the RIPs speed (i.e., raise or reduce the speed) by individual or group RIPs and to runback RIPs. Finally, the VDU of Flow-Power Map displays the percent power, percent core flow, and the relationship between power and core flow (as shown in Figure 4).

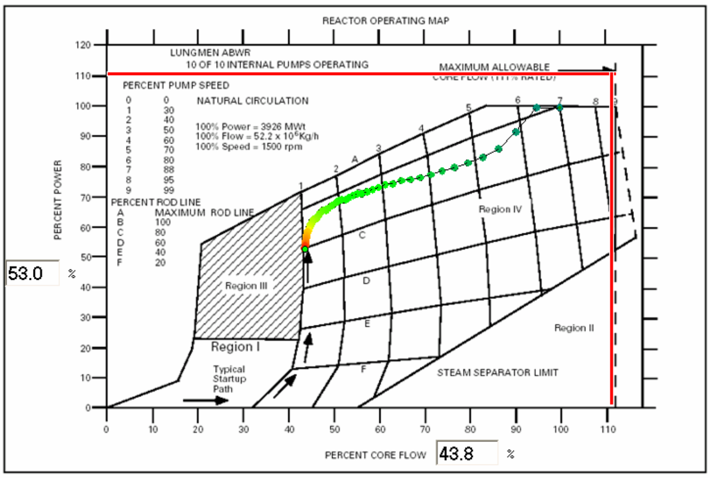
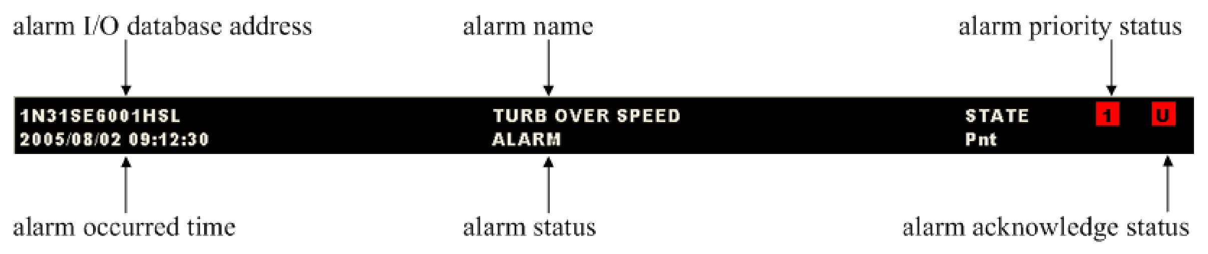


Fig. 4. Flow-Power Map

3.2 Alarm processing

The alarm processing has been developed in Visual Basic program, and includes alarm manager display (Current Alarm Display, CAD) and system alarm tile display. All alarm signals created from PCTRAIN system and displayed on VDUs of CAD and of system alarm tile display respectively. Each alarm signal is displayed by using different color for different priority of occurred events on VDU of alarm tile display and offering the list of occurred events to operators on VDU of CAD.

The VDU of CAD is specific explanation of alarm status on list window including alarm I/O database address, alarm occurred time, alarm name, alarm status, alarm priority status, and alarm acknowledge status. The order of alarm signals in CAD is by occurred time. The alarm priority is from priority-1 to priority-4 in the alarm priority status, and the statuses of alarm acknowledge include 3 types: in-alarm unacknowledged, in-alarm acknowledged, and return-to-normal. For instance, as shown in Figure 5, the displayed alarm signal is TURB (turbine) over speed, occurred at 09:12 am, priority-1 alarm, and in-alarm unacknowledged status.



1N31SE6001HSL
2005/08/02 09:12:30
TURB OVER SPEED
ALARM
STATE
Pnt

Fig. 5. The specific information on list window

The VDU of system alarm tile display provides alarm information by five tile groups; each group involves 13-27 alarm signals, each alarm signal presents alarm priority status. The priority-1, 2, 3, and 4 alarms are represented by the red alarm signal, yellow alarm signal, white alarm signal, and purple alarm signal respectively on the VDU. Each alarm signal only displays the highest priority alarm if there is more than one alarm. When an alarm occurs, the alarm signal twinkling with auditory alarm on the corresponding alarm tile (i.e., in-alarm, unacknowledged status) until the alarm has been acknowledged on VDU of CAD (i.e., in-alarm, acknowledged status). Finally, the alarm signal is twinkling slowly with auditory alarm in 3 seconds and then disappears if the alarm returns to normal status.

4. Assessment of the alarm system simulator

Two experiments (Experiment Ⅰ and Experiment Ⅱ) were conducted to investigate the effect of reset modes on performance of Experts and Novices and on performance of Novices under varying alarm loads.

4.1 Experiment Ⅰ

The experiment Ⅰ was conducted to investigate the effects of auto-reset alarm system and alarm system requiring manual reset on performance of Experts and Novices. This experiment was expected to understand the practicability of auto-reset alarm system on FNPP in Taiwan. Two alarm systems, one providing auto-reset function and the other requiring manual reset, were used to compare individual performance using the alarm system simulator. This section is divided into the following parts: experiment scenarios, participants, apparatus, independent variables, experiment design, dependent variables, and experiment procedures.

4.1.1 Experiment scenarios

After discussed with related managers and operators who have operating experience more than 10 years on nuclear power plant in Taiwan, the procedure of Load Rejection was selected in this experiment. The flowchart for the procedure of Load Rejection is shown in Figure 6. The procedure of Load Rejection is an abnormal operating procedure (AOP). Once the events of this procedure occur, five alarm signals including ALL RIP RUNBACK, SCRRI, 345KV BUS PROT LO, OVER

SPEED TRIP (electrical), and SCRRI MOVEMENT REQUIRED will be shown on the VDUs of CAD and system alarm tile display. Each alarm signal will be auto-reset or manual reset after each event returned to normal. Both reset modes of the alarm system, the system alarm tile display and CAD not only present the above-mentioned alarms signals but display other related or false alarm signals. The experimental task is described as follows,

The above-mentioned five alarms displayed on the RFC, SBPC (Steam Bypass and Pressure Control), EPD (Electrical Power Distribution), TURB, and RCIS alarm tile groups respectively after the events of Load Rejection occur for thirty seconds. The alarms of 345KV BUS PROT LO and SCRRI are covered by higher priority alarms, which are related or false alarm signals, on system alarm tile. Next, several of related or false alarms are created to covered return-to-normal alarm signals after the RTP less than 28% for 5 seconds (please refer to Figure 6). The related and false alarms are priority-1 alarms, which included SBPC C85 SYS TRP, UAT-A XFMR DIFFERENTIAL PH-A, TURB TURNING GEAR, SBPC DEH CPU A AND B FAIL, ABT XFMR DIFFERENTIAL, TURB TURNING GEAR, and RCIS TROUBLE. The operators have to judge the procedure from large number of alarm signals as well as detect the return-to-normal alarms.

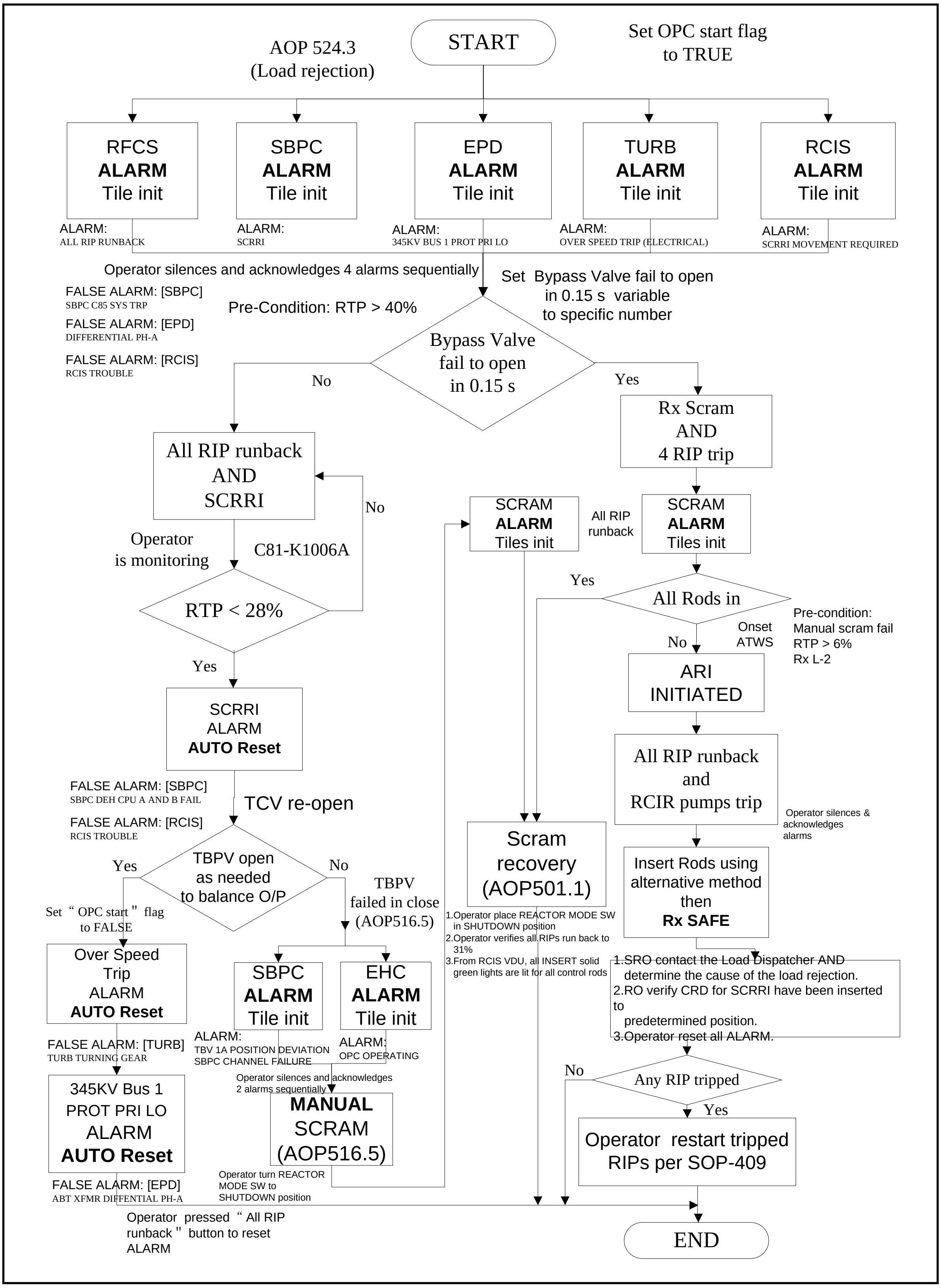


Fig. 6. Flowchart for the procedure of Load Rejection

4.1.2 Participants

Two operators of FNPP in Taiwan, who have operating experience in traditional control room ranged from 6 to 12, and four participants, who attended training course of advanced boiling water reactor for 96 hours, participated in this experiment. It was anticipated to obtain different strategies and performance between expert and novice within auto-reset and manual reset alarm systems on performance of operating the reactor system from the experiment.

4.1.3 Apparatus

The simulate alarm system was described earlier in sections 3. For this experiment, the alarm system simulator was designed to represent the procedure of Load Rejection. The system used a personal computer with PCTRAN system and alarm processing and had been developed with the same interface and procedures but different reset models. The series of designed alarm events were conducted with either of the two modes of the simulate alarm systems: one was auto-reset system and the second one was manual reset system. The whole information were displayed on VDU respectively. Using auto-reset system, the occurred alarm signals will be automatically reset after the related event was recovered. However, the manual reset system requires operators to click related buttons on interface by a keyboard or a mouse.

4.1.4 Independent variables

In this experiment, the independent variables were “reset modes of the alarm system” and “operating experience”. The reset modes of the alarm system contained two levels: an auto-reset alarm system and the alarm system requiring manual reset. An auto-reset alarm system is automatically reset for returned-to-normal alarms. If the current system requires additional actions, new alarms will be raised as an indication. Unlike an auto-reset alarm system, the manual reset alarm system require operators to take action after the alarm clears identified from all priority-1 and priority-2 alarms. The operating experiment also contained two levels: expert and novice. The experts are selected from FNPP in Taiwan who have operating experience in traditional control room more than five years.

4.1.5 Experimental design

In this experiment, each participant took part in four task runs, each task run had the same scenarios but different reset mode. Two task runs using auto-reset system and two task runs using manual reset system, and the order of each task was randomized. A within-subject design was conducted on both reset modes of the alarm system. In total, six operators participated, two operators of expert and four operators of novice.

4.1.6 Dependent variables

The dependent variables in this experiment were described as follows,

- Operation time: The total time operators spent in decision-making and action recorded from the start-up of internal pumps operating to the end of the procedure events returned to normal.

- Situation Awareness (SA): SA is formally defined as a person's perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and perfection of their status in the near future (Endsley, 1995a). SA involves perceiving of the elements in the environment (Level 1 SA), understanding what those factors mean, particularly when integrated together in relation to the decision maker's goals (Level 2 SA), and at the highest level, projecting of future status to allow for timely and effective decision making (Level 3 SA) (Endsley, 1995b). In this experiment, SA included objective measure and subjective measure and was administered after each task run. In order to estimate the value of level 1 and 2 SA from participants, the tests of objective measure involved judging procedure, selecting related priority-1 alarms, and detecting false alarms. For estimating the satisfaction of level 1, 2, and 3 SA from participants, five questions with 5-point Likert scales (1=strongly agree, 5=strongly disagree) were given for participates' self-assessment.
- End-of-task subjective rating: The end-of-task subjective rating was also administered after each task run, which includes task workload and preferred reset mechanism. The NASA Task Load Index (TLX; Hart & Staveland, 1988) is a commonly used rating scale based on six independent factors (mental demand,

physical demand, temporal demand, performance, effort, and frustration) associated with the experience of workload and provides an assessment of individual workload (Entin & Entin, 2001). In this study, the NASA TLX with 21-point rating scales is supplied for operators to indicate the workload level of each dimension. Finally, an option questions were supplied for participants to select his/her preferred reset mechanism in this experiment.

- End-of-experiment subjective rating: Five questions with 5-point Likert scales (1=strongly agree, 5=strongly disagree) were given for participates' self-assessment of auto-reset alarm system after the experiment. The subjective opinion and open questions were also given for participates' feedback of information display, alarm processing, and the mode of alarm system.

4.1.7 Experimental procedure

Each participant conducted four task runs; each task had the same scenario but different order and different reset modes of the alarm system. After all participants took part in learning course and operating practice for four hours, they participated in the series of experimental task for 0.5 hour.

4.1.8 Hypothesis

In this experiment, it was hypothesized that both participants of Experts and Novices using automatic reset alarm system on the procedure of Load Rejection in FNPP would experience less workload and operation time compared to those who using manual reset system. It was expected that the automatic reset alarm system may be used practicably in real FNPP.

4.2 Results of Experiment Ⅰ

4.2.1 Operation time

The performance times (in seconds) were compared with t-test between different set of factors of interest, and the summary of results is shown in Table Ⅰ. First, the performance times of all twelve subjects using automatic and manual reset were compared. Automatic reset is significantly faster than manual reset (p=0.011). Second, the performance times of automatic vs. manual were compared for either Expert group or Novice group. Similar to the grand comparison, automatic reset is significantly faster than manual reset in either group (p=0.032 for Experts and 0.001 for Novices). Third, the performance times of subjects in Expert group and Novice group were compared while using automatic reset or manual reset. The operation time of Experts and Novices were not significantly different when using auto-reset system, but the operation time of Novices is significantly faster than of Experts when using manual reset system.

Table 1

Summary of descriptive statistics and t-test significance of performance time

Source	Comparison items	N	Mean (Std. Deviation)	t-test sig. (2 tailed)
All participants	Automatic	12	169.50 (34.81)	**0.011 ***
	Manual	12	224.17 (58.53)	
Experts	Automatic	4	193.50 (55.82)	**0.032 ***
	Manual	4	293.75 (45.82)	
Novices	Automatic	8	157.50 (8.64)	**0.001 ***
	Manual	8	189.38 (18.26)	
Auto-reset	Expert	4	193.50 (55.82)	0.91
	Novice	8	157.50 (8.64)	
Manual reset	Expert	4	293.75 (45.82)	**0.00 ***
	Novice	8	189.38 (18.26)	

4.2.2 Results of SA measure

- Objective measure: The results of the objective questions are from 0 to 2 (0= incorrect answer, 1= 1 correct answer, 2= 2 correct answers). The score of an option question for judged procedure was compared using the Fisher’s exact test, and of two multiple choice questions for selected priority-1 alarms and detected false alarms were compared using the Kolmogorvo-Smirnov (K-S) test. Both results indicated that there were no significant difference between Experts and Novices and between manual and auto-reset on objective tests. It might be due to insufficient number of participants even though the error rate of Experts on procedure judgment was 0 but those of Novices was 50%.
- Subjective measure: The results of the subjective ratings for each items are from 1 to 5 (1= strongly agree, 5= strongly disagree). The results of a K-S test indicated

that subjective ratings of SA was not significantly different between Experts and Novices ($p<0.05$). The agreement percentages on SA of Experts and Novices are 43% and 42% respectively.

4.2.3 End-of-task subjective rating

The results of end-of-task subjective ratings included TLX, preferred reset mechanism, and VDUs and are analyzed as following,

- NASA TLX: The rating scales of TLX for each items are from 0 to 100 (0= lowest workload, 100= highest workload). NASA TLX scores were compared using t-test between different set of factors of interest, and the result is summarized in Table 2. At the significance level of 0.05, only two of the comparisons are significant, which are marked as bold in the table. They are comparison of effort between Automatic and Manual within Novice ($p=0.03$), and comparison of performance between Expert and Novice using Manual ($p=0.02$). It indicated that the Novices using auto-reset alarm system had significantly higher workload on effort than using manual reset, and the Novices had significantly higher workload on performance when using manual reset than the Experts did. The effort defined as “how hard did you have to work (mentally and physically) to accomplish your level of performance?”, and the performance defined as “How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?” in the TLX. Additionally, according to Table 2, most of values in each item and total are lower than 50.

Table 2

t-test of NASA TLX scores between different set of factors of interest

Score mean/ t-test sig. (2 tailed)	Mental	Physical	Temporal	Effort	Performance	Frustration	Total
Automatic	45.83	40.00	38.33	51.67	32.92	39.17	47.01
Manual	44.17	37.92	36.25	42.50	36.67	37.92	43.68
p value	0.86	0.81	0.82	0.19	0.60	0.83	0.55
(Expert)							
Automatic	52.50	47.50	42.50	50.00	22.50	30.00	50.00
Manual	47.50	37.50	42.50	52.50	20.00	32.50	48.75
p value	0.86	0.64	1.00	0.88	0.78	0.71	0.94
(Novice)							
Automatic	42.50	36.25	36.25	**52.50**	38.12	43.75	45.52
Manual	42.50	38.13	33.13	**37.50**	45.00	40.63	41.15
p value	1.00	0.83	0.72	**0.03***	0.39	0.70	0.20
(Automatic)							
Expert	52.50	47.50	42.50	50.00	22.50	30.00	50.00
Novice	42.50	36.25	36.25	52.50	38.12	43.75	45.52
p value	0.54	0.51	0.71	0.83	0.10	0.21	0.65
(Manual)							
Expert	47.50	37.50	42.50	52.50	**20.00**	32.50	48.75
Novice	42.50	38.13	33.13	37.50	**45.00**	40.63	41.15
p value	0.70	0.94	0.42	0.11	**0.02***	0.24	0.30

- Preferred reset mechanism: The results is shown in Figure 7, one can see that there are 63% Experts who preferred using alarm system requiring manual reset; however, there are 81% Novice who preferred using auto-reset alarm system.

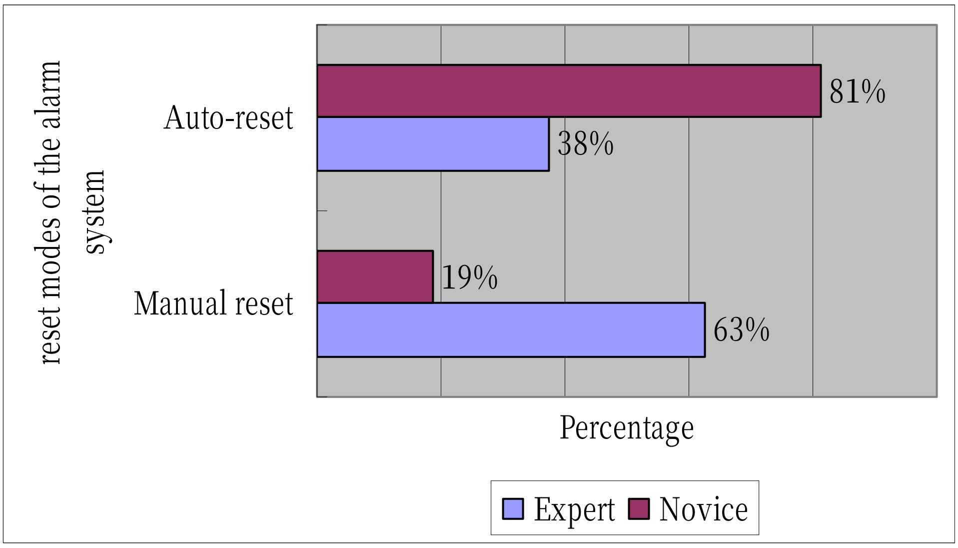


Fig. 7. Agreement percentages of Experts and Novices on reset modes

4.2.4 End-of-experiment subjective rating

The results of a K-S test indicated that subjective ratings of using auto-reset alarm system were not significantly different between Experts and Novices (p>0.05). An average percentage of agreement on auto-reset from both Experts and Novices is 14%. Experts and Novices also offered their suggestions and feedback on opened questions, and the results are shown in Tables 3 and 4 respectively. Due to Experts have plenty of field experience on NPPs, they suggested that the auto-reset system should be improved by representing the alarm history on real-time, supporting a clear way to display returned-to-normal alarms, and adding the function of manual reset (see Table 3). Unlike Experts, Novices addressed advantages as well as limitations of auto- and manual reset alarm system. As shown in Table 4, there were 75% Novices who addressed that using auto-reset might reduce number of alarms and operating errors and 100% Novices who indicated that using manual reset might assist operators to handle all alarms' situation. Finally, all Experts and Novices also stressed the importance of training to the monitoring of wide display panels.

Table 3
The suggestions of auto- and manual reset modes from Experts

	Suggestions
Automatic reset	1. The alarm history should be displayed in real time or in 3 seconds 2. Enhance the way to display the return to normal alarm 3. Add the function of manual reset model on auto-reset alarm system
Manual reset	1. Because the manual reset mode on simulator is different from traditional manual control, the manual reset interface should be improved or plenty of practice should be supported to operators.

Table 4
The feedback of auto- and manual reset modes from Novices

		Suggestions	Percentage
Automatic reset	Advantage	Reduce number of alarms and operating errors	75%
	Limitation	Reduce operators' vigilance especially for priority-3 or 4 alarms	25%
Manual reset	Advantage	Easy to handle each alarms' situation.	100%
	Limitation	Spend a long time on checking and resetting alarms	50%

4.3 Experiment Ⅱ

The results of Experiment Ⅰ indicated that Novices had higher workload on effort when using auto-reset alarm system than when using manual reset alarm system and higher workload on performance when using manual reset system than Expert had (please refer to Table 2). In order to understand the effect of reset modes to Novices on workload more specific, the Experiment Ⅱ was conducted to investigate the effects of auto- and manual reset modes in varying alarm loads on performance of Novice.

4.3.1 Experiment scenarios

Two tasks of the Load Rejection procedure were selected in this experiment (please refer to Figure 6), and are described as follows,

- Task 1: the five alarm signals, ALL RIP RUNBACK, SCRRI, 345KV BUS PROT LO, OVER SPEED TRIP (electrical), and SCRRI MOVEMENT REQUIRED, displayed on the RFC, SBPC, EPD (Electrical Power Distribution), TURB, and RCIS alarm tile groups respectively. The operators have to judge the procedure from alarm signals as well as detect the "return-to-normal" alarms until the five alarms return to normal.
- Task 2: the five alarm signals, ALL RIP RUNBACK, SCRRI, 345KV BUS PROT LO, OVER SPEED TRIP (electrical), and SCRRI MOVEMENT REQUIRED, displayed on the RFC, SBPC, EPD (Electrical Power Distribution), TURB, and RCIS alarm tile groups respectively. After the RTP less than 28%, the other five alarm signals, SCRAM RODS IN, SBPC Channel A, TBV 1A Position Deviation, and OPC OPERATING occurred and displayed on RPS, SBPC, and EHC alarm tile groups respectively. At the same time, the two higher

related alarms covered alarm signals on RPS and EHC respectively. The participants have to judge the procedure from a large number of alarm signals as well as detect the return-to-normal alarms.

4.3.2 Participants

Four participants, who attended training course of advanced boiling water reactor for 96 hours, participated in this experiment. It was anticipated to obtain different strategies and performance between task 1 and task 2 within auto-reset and manual reset alarm systems on performance of operating the reactor system from the experiment.

4.3.3 Independent variables

In this experiment, the independent variables were “reset modes of the alarm system” and “alarm loads”. The reset modes of the alarm system contained two levels: an auto-reset alarm system and the alarm system requiring manual reset. The alarm loads also contained two levels: 5 alarm signals event in lower alarm load (i.e., task 1) and 10 alarm signals with 2 related and false alarms event in higher alarm load (i.e., task 2).

4.3.4 Experimental design

In this experiment, each participant took part in four task runs, two task 1 and two task 2 with auto- and manual reset modes respectively. The order of each run was randomized. A within-subject design was conducted on two reset modes of the alarm system and two alarm loads.

4.3.5 Experimental procedure

Each participant conducted four task runs. After all participants took part in learning course and operating practice for four hours, they participated in the series of experimental task for 1 hour.

4.3.6 Dependent variables

The dependent variables in this experiment contained operation time, SA, and subjective measures, which the same with Experiment Ⅰ. In this experiment, SA also included objective measure and subjective measure and was administered after each task run. Since the results of Experiment Ⅰ on SA were not statistically significant, the questions of objective measure had been modified to be more specific. The tests of objective measure involved perceiving alarm/system, judging procedure, selecting related priority-1 alarms, and predicting event in the near future.

4.3.7 Hypothesis

In this experiment, it was hypothesized that the participants using automatic reset system would experience less workload and higher satisfaction compared to those using manual reset system on the procedure of Load Rejection in FNPP.

4.4 Results of Experiment Ⅱ

4.4.1 Operation time

The performance times (in seconds) were compared with t-test between different set of factors of interest. There were no significant difference between auto- and manual reset in task 1 and task 2 ($p>0.05$).

4.4.2 Results of SA measure

The objective ratings were compared with t-test between using auto-reset and requiring manual reset in varying alarm loads. The results indicated that there was significant difference between auto-reset and manual reset in task 2 (p=0.031), others were not significantly different. Additionally, the subjective ratings were compared with K-S test between using auto-reset and manual reset in task 1 and task 2. The results indicated that there were no significant difference between auto-reset and manual reset and between task 1 and task 2 (p>0.05).

4.4.3 End-of-task subjective rating

NASA TLX scores were compared using t-test between different set of factors of interest. The results indicated that there were no significant difference between auto- and manual reset in both task 1 and task 2 (p>0.05). The range of total TLX for participants is from 27.50 to 55.83. Additionally, the results indicated that there were 87.5% participants who preferred using auto-reset alarm system.

4.4.4 End-of-experiment subjective rating

The results indicated that the percentage of agreement on using auto-reset alarm system is 80%. Although they may handle status of the reactor system well and have higher vigilance when using manual reset alarm system, the participants still preferred using auto-reset alarm system. The participants also suggested that the information on CAD would be easier to read if the alarms are ordered by priority on opened questions.

5. Discussion

5.1 Effect of using auto-reset alarm system in the alarm system simulator

When using automatic reset, subjects took less time in completing the task than when using manual reset for either Expert group or Novice group (please refer to Table 1). This is due to the fact that when returned-to-normal alarms are automatically reset, the subject doesn’t have to detect the alarm status change and take action (that is, reset the alarm). However, subjects commented about being ill informed when accomplishing the task with automatic alarm reset. When the comparison between Expert group and Novice group subjects of Expert group revealed a trend of taking longer time in the completion of the task, no matter which reset mechanism they were using. Since subjects in Expert group are well trained and licensed operators, they tend to collect and analyze as much information as possible before they take any action. Subjects in Expert group revealed higher level of cautiousness than subjects in Novice group.

From the summary of NASA TLX scores in Expert Ⅰ (Table 2)T, only comparisons of effort between Automatic and Manual within Novice (p=0.03), and performance between Experts and Novices using Manual (p=0.02) were significant. Most of comparisons of each workload item between Experts and Novices, the scores were not significantly different either using automatic or manual reset alarm system, and most of the TLX’s results are less than 50.

From the results of end-of-task subjective ratings, one can see that Experts preferred using manual reset alarm system (as shown in Figure 7). During the post-experiment interview, they also mentioned about preferring manual reset system if there are only a few occurrences of alarms and the situation could wait; however, if there are bunch of alarms and when the situation is very urgent, auto-reset is preferred. This result is interesting when compared to the result reported in NUREG-6691 (O’Hara et al., 2000). In NUREG-6691, significant interactions were found between alarm system characteristics and scenario complexity. Although the characteristics considered therein didn’t include alarm-reset mechanism, operators’ preferences of alarm system depended upon the phase of a disturbance and the number of alarms. Also, the results of Experiment Ⅱevidenced that using auto-reset alarm system and using manual reset system in task 2 was significantly different on the objective measures of SA and indicated that the auto-reset alarm system may assist participants to have higher SA when there are a large number of alarms and a disturbance from false alarms.

In both Experiment Ⅰ and Ⅱ, most participants of Novices preferred using automatically reset alarm system. In Experiment Ⅰ, there were 75% Novices who addressed that using auto-reset system might reduce workload and operating errors (as shown in Table 3). Since subjects in Novice group are unfamiliar with NPP operation, they tend to skip unnecessary reset action and concentrate on perceiving and tracking alarm signals. From the results of end-of-experiment subjective rating, an average percentage of agreement on automatic reset from all participants indicated that they remained neutral on degree of satisfaction at using auto-reset system. Because using auto-reset, the alarm could be automatically reset and disappeared from the wide display panel and current alarm display, Experts suggested that the system should have both of auto- and manual reset functions for switch during different situations and Novices addressed that a clear way to display different priority alarms should be offered.

Based on the results, the advantages as well as the limitations of the auto-reset alarm system are discussed as follows,

- The advantages of automatic reset alarm system: Firstly, the auto-reset mode is easy to use and to adapt especially for Novices. Secondly, the auto-reset mode may assist participants to deal with the plant accidents in the control room when the situation is urgent and when there are bunch of alarms. Thirdly, participants considered that using the auto-reset mode might reduce workload and operating errors.
- The limitations of automatic reset alarm system: Firstly, the operators may neglect the reset-to-normal alarm if the alarm is informed unclear. In operating control

room, the total alarms are more than four thousand and the highest number of alarms in emergent situations is possible more than one thousand alarms. It is important to announce each reset-to-normal alarm to operators, especially in emergent situations. In the experiment, the participants addressed that it is hard to catch the announced alarm from the visional and auditory alarms in 3 seconds. Secondly, operators may get lost some alarm information to increase the potential damages in running safety of NPP. In NPP, operators have to handle every critical situation from alarm signal to make right decision. Therefore, the participants of Experts stressed that it is important to acquire alarm information from alarm history display in real time if operators could not catch the alarm information on CAD or system alarm tile display. Thirdly, it would take a long time to adapt the auto-reset alarm system for Experts.

5.2 Study limitations

In the experiments, the Novices and Experts are major participants. The AOP of Load Rejection, which is a low workload but important procedure, was selected applicable to Novices, because the Novices have a limited capability for operating control room. In NPP, the operating procedure contained system operating procedure (SOP), AOP and emergency operating procedure (EOP). The alarm signals occurred in AOP and EOP. The AOP is a maintenance and routine operation, and the EOP is an unusual and critical operation to ensure plant safety. When the events of AOP could not be handled well, the related events would be occurred and then maybe get into the EOP. In this study, the results could only reveal that the auto-reset alarm system may be practicable in AOP of Load Refection, but in EOP or several special procedures still need an extra experiment to investigate it. The auto-reset mode may impact several special procedures; for instance, if the operators did not catch the announced alarm that the high water level status return to normal water level status, the feedwater pump keep working to occur the unnecessary accident of tripping system in low water level status.

6. Conclusion

The automatic reset alarm system has been evaluated with the alarm system simulator. From the evaluating results, it was shown that using the auto-reset mode might significantly reduce operation time for both Expert and Novice groups and raise SA for Novices under a large number of alarms situations. Also, the majority Novices preferred using auto-reset alarm system. Experts preferred auto-reset alarm system under high workload situation but preferred manual reset alarm system if there are only a few occurrences of alarms and the situation could wait. The majority Experts expressed that alarm processing should be performed with caution, and preferred alarm system requiring manual reset.

Summarized the results, the auto-reset alarm system is practicable in an advanced control room of Load Rejection procedure if the operators are Novices; however, the majority operators in FNPP are experts who are going to come from first, second, or third NPP in Taiwan. Once the operating control room in FNPP applied auto-reset alarm system in operating control room, the experts have to take a long time to practice and adapt to it. It may also bring some potential crises to endanger running NPP safety. For ensuring public safety and operators' work satisfaction in auto-reset alarm system, the Experts have to accept the recent system, and the system have to support the information of alarm history in real time. Finally, the practicability of auto-reset alarm system in EOP or several special situations is still unknown. In the future study, it is an important issue to investigate that whether or not the alarm system in control room can be completely automated.

References

Endsley, M.R., 1995a. Measurement of situation awareness in dynamic systems. Human factors 37(1), 65-84.

Endsley, M.R., 1995b. Toward a theory of situation awareness in dynamic systems. Human factors 37(1), 32-64.

Entin, E.E., Entin, E.B., 2001. Measures for evaluation of team process and performance in experiments and exercises. In: Proceedings of the 6th International Command and Control Research and Technology Symposium, Annapolis, Maryland June 19-21.

Hari, S., Hassan, Y.A., McFarland, A.R., 2005. Computational fluid dynamics simulation of a rectangular slit real impactor’s performance. Nuclear Engineering and Design 235, 1015-1028.

Hart, S.G., Staveland, L., 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P.A. Hancock & N. Meshkati (Eds.), Human mental workload (pp.139-183). Amsterdam: Elsevier.

Huang, F.H., Hwang, S.L., 2003a. Design and evaluation of computerized operating procedures in nuclear power plants. Ergonomics 46(1), 271-284.

Huang, F.H., Hwang, S.L., 2003b. Effect of the computerized graphic interface on Emergency Operating Procedure－a case study for nuclear power plants.

Asian Journal of Ergonomics 4(1), 11-24.

Miller, W.H., 1983. Design and implementation of a simple nuclear power plant simulator. Nuclear Instruments and Methods 205, 511-516.

O'Hara, J. M., Brown, W. S., Lewis, P. M., Persensky, J. J., 2002. Human-system interface design review guidelines (nureg-0700, rev. 2). Washington, DC: U.S. Nuclear Regulatory Commission.

O'Hara, J. M., W. S. Brown, et al., 2000. The Effects of Alarm Display, Processing, and Availability on Crew Performance (NUREG-6691). Washington, DC, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

Rasmussen, J., 1983. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. IEEE Transactions on Systems, Man and Cybernetics 13, 257-266.

Rauterberg, M., 1998. About the importance of auditory alarms during the operation of a plant simulator. Interacting with Computers 10, 31-44.

Sheridan, T. B., 2002. Humans and automation: System design and research issues. New York, Wiley.

Shi, L., Liu, H., Yang, X., Gao, Z., Dong, Y., Zhang, Z., 2004. A personal computer-based simulation-and-control-integrated platform for 10-MW high-temperature gas-cooled reactor. Nuclear Technology 145 (FEB.), 189-203.

Stanton, N., 1994. Alarm initiated activities. In N. Stanton (Ed.), Human factors in alarm design. London.

Wickens, C.D., Hollands, J.G., 2000. Engineering psychology and human performance. Upper Saddle River, New Jersey: Prentice-Hall Inc.