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DEVELOPMENT OF THE NEWLY ADVANCED ALARM SYSTEM FOR APWR PLANT

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ABSTRACT

We have been developing AMCB (Advanced Main Control Board) for APWR consisting of a large overview display and an operator console. We have adopted the alarm prioritizing functions, which are already in use in the existing Japanese PWR plants, for easier identification of the high priority alarms. Moreover, we have developed an alarm system with a large overview display, which presents alarms on the plant process flow diagram. This enhances the location aids and pattern recognition in the alarm identification process. This time, we made further improvement and studies for better and various functions combining a large overview display with a CRT display. We determined the alarm system specification as follows, taking account of flexible alarm recognition processes.

(1) The high priority alarms can be identified upon the LOD (large overview display). On the display, the alarms are described on the plant flow diagram, and the alarm status is shown on the fixed position of process or equipment symbols.

(2) Other alarms are identified on large overview display and on CRTs using a hierarchical process.

(3) The alarm messages are divided into 4 different groups according to the plant systems, thus enabling to undertake the countermeasure operations, using only the CRT.

Moreover, we integrated a computerized ARPs (Alarm Response Procedures) into the alarm system.

1. INTRODUCTION

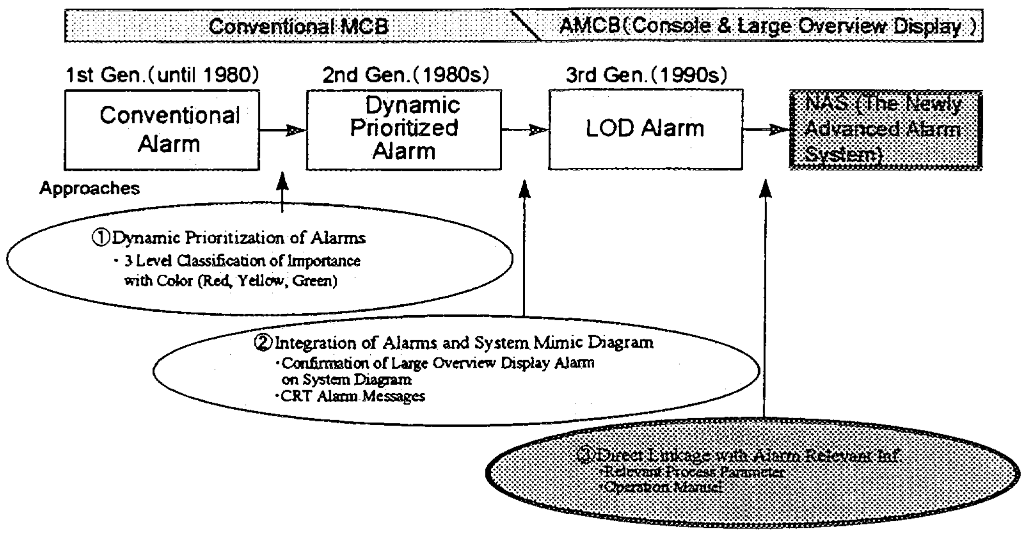
Compared with the conventional alarm display system with the hardware alarm tiles and the textual alarm messages on CRTs, the alarm display system with a software operation panel gives a substantially larger flexibility of designing. Consequently, many types of alarm system have been so far developed and proposed. We must deliberate to set the most optimum specifications for our purpose.

In this context, in developing the alarm system, adding to the possible approach by the improvement of the conventional systems, we have to pursue the optimization of software alarm specifications to the inherent requirements of the alarm functions. Also, we may have to take into consideration preservation of the traditional design philosophy and the skill of operators.

Bearing that in mind, we have developed NAS (the Newly Advanced Alarm System) for the APWR power plant. The development has been made in a close collaboration between the Japanese PWR utilities and the MITSUBISHI Group.

2. HISTORY OF DEVELOPMENT

The evolution of the alarm system of the PWR plants in Japan is shown in Figure 1.



Evolution of the Alarm System

2.1 Conventional Alarm System

The alarm system of the conventional MCB consisted mainly of the hardware alarm tiles. Its principal technology reposed on the alarm grouping and the rules of the alarm tiles arrangement in order to take advantage of so-called location aid and pattern recognition.

2.2 Dynamic Prioritized Alarm System

Although high availability of the plants has been maintained in Japan with the conventional alarm system, the accident of the TMI-2 revealed that too many alarm activating at the same time have the operators overburdened with alarm recognition. As a result, the system needed improvement.

The main purpose of the development was to avoid that any important alarm should be overlooked, and the alarm prioritizing technology was the main view point of the alarm system. In consideration that it was necessary to keep the number of the alarms within a range where operators can recognize all the high priority alarms, the developed system was based upon the following rules:

(a) Prioritization of alarms with multi-setpoint relationship

When an alarm with higher setpoint level is activated, alarm messages at lower levels are no longer considered.

(b) Prioritization by cause-and-consequence relationship between alarms

When "Charging Pump Trip" alarm is activated, Charging pump outflow is decreased. In this case, the cause alarm "Charging Pump Trip" is set as a high priority alarm and the consequence alarm "Charging Pump Outflow Low" is set as a low priority alarm.

(c) Prioritization according to the operation mode

An alarm related to the process parameters and an equipment of the system not in use is not considered as a highest priority alarm.

While the Reactor is in trip, "Control Rod at Reactor Bottom" alarm is set as a low priority alarm.

With those prioritization logic processing's, the alarms are categorized into the 3 priority levels; the highest priority is attributed to red, then yellow, and the lowest is to green. This clarified the high priority (red) alarms to which the operators must response. At the issue of the evaluation operation, the operators recognized the improvement, particularly in the higher detection rate of secondary failure.

2.3 Alarm System of the AMCB Using Large Overview Display

We have already developed AMCB for APWR. In this development, we established an alarm system with a hierarchical alarm recognition process, mentioned as follows:

(a) Recognition of alarm activation on the large overview display

(b) Identification of detailed textual alarm messages on CRTs of the console

Taking account of that the conventional alarm system relies largely upon the pattern recognition effect of the alarm tiles arrangement, we have aimed to enable an more instinctive and direct identification of the location of the alarm, making use of the integrated display of the plant system diagram and the alarms.

At the same time, the alarm system displays alarms categorized according to the priority level on a CRT. Categorization is carried out likewise mentioned above (2).

The validation test proved that the alarm system applied to AMCB enables higher recognition capacity of the alarms than the existing alarm systems. The questionnaire to the operators, however, revealed that there remain still several problems to be resolved.

3. PROCESS OF DEVELOPMENT

The present development has been carried out with the purpose of bringing solution to the alarm problems of AMCB. In developing the new system, we set the basic design principle based on the search of the solutions to the problems, extraction of the improvement items from the present alarm system specification, operator needs, and analysis of the requirements to the alarm system. Furthermore, we have conducted static and dynamic validation test before setting the final specifications of NAS.

4. EXTRACTION OF THE IMPROVEMENT ITEMS

4.1 Analysis of the Improvement Items for the Alarm System of AMCB

The following problems have been extracted throughout the validation tests.

(a) Alarms on the large overview display enable easier recognition of the defective part location, but it is difficult to identify specific alarm context.

(b) It is difficult to find the detailed corresponding alarm on the CRT to a group alarm on the large overview display. Therefore, it is required that the precise alarm message on the CRT is identified smoothly after recognition of the group alarm on the large overview display is required.

(c) Some reinforcements of operation support function after alarm recognition are required.

4.2 Inquiry to the Operators on their Needs and its Analysis

Prior to undertaking the new development, we have conducted inquiries to the operators on their needs in regard to the alarms. As a result, we have ascertained, as it had been pointed out before, continuous display of the alarm tiles and the maintenance of pattern recognition effect with the display position. Also, we have made sure of their needs for further decrease in number of alarms and in display of ARPs at alarm activation.

5. REQUIREMENTS

Admitting that the basic function of alarm is to alert the operators that some event has occurred, we have to put into place a more complete system which can play adequate roles in accordance with the process of operators actions at alarm activation along with each of the following phases:

1. Detect of anomalies and alert the operation crew
2. Inform about the priority and the situation
3. Guide the operation response
4. Confirmation of recovery

In this process, easy detection of anomalies is important not only for the primary failure but also for secondary failures. In developing this system, we have conducted thorough studies in order to meet the above requirement to provide the most adequate information for each process. Also, we have endeavored to have the improvement items and the needs of the operators reflected.

6. BASIC DESIGN PRINCIPLE

6.1 Detection of Anomalies

(a) Recognition of alarm

We have adopted the alarm display system taking full advantage of a large overview display, intending to make easier the recognition of alarm location and to alert the whole operation crew to the alarm. For this purpose, display of the alarms is integrated with the plant process flow diagram on the large overview display. The alarms which are not categorized to the alarms on the diagram are grouped otherwise.

(b) Detection of secondary failure

We have intended to make easier the detection of secondary failures even when many alarms are being raised. In order to make it easier, we have the following ways of detection:

- Direct detection: automatic checking of the inter-lock actuation
- Indirect support: reduction of the operators' burden in the alarm recognition by reducing the number of the alarms with the alarm prioritization

Direct Detection of Secondary Failure

We have focused upon the serious failures which may affect the safety and the operation of the plant and upon those for which we can precisely define the extent of support. In this meaning, we have set our target on the misfunction and malfunction of the equipment related to the reactor protection system and engineering safety features.

We decided to display together, for facilitating a secondary failure detection ,with a "OK" or "NG" status information on the screen being checked the integrity of the alarm related interlock actuation by the computer. We have added new alarm items, such as "Malfunction of Control Rods at the Reactor Trip".

Indirect Support

We have reinforced the alarm prioritization in order to reduce the number of alarms that require some countermeasures. At the same time, the alarms are categorized into some groups with the view to reduce the burden of alarm recognition. However, since a complicated alarm prioritization logic may lead to increase the cognitive burden, we are adopting only those which are simple and comprehensible and give a single and clear reply.

In order to reduce the human error probability, we have set target to provide less than 10 alarms in each group in view of easier search of information from the alarm list on a CRT.

6.2 Identification of the situation

For the purpose of easier identification of the situation at alarm activation, we have integrated the alarm related information. Also, for the request of further detailed information, we made the most adequate allocation of the CRT displays corresponding to each alarm item.

(a) Provision of complementary information

As complementary information related to the alarm, we decided to add the process values of the alarm parameters and their trends to the alarm all the time.

(b) Request for related CRT screens

With a view to allowing a smoother shift to the precise plant status recognition at alarm activation, related screens can be called with a one-push request on alarm messages. Operators can get CRT displays both for process status recognition and interlock and system status recognition by touching the related area of the alarm message on the display.

(c) Some reinforcements of operation support function after alarm recognition are required.

6.3 Countermeasures

We have provided easy access to ARPs in order to ensure the appropriate countermeasures to the activated alarm. By touching the alarm name on the screen, operators can request corresponding operation procedures. It makes sure, completing the memory of the operators, that no part of the necessary measures should be neglected and that the operation should be conducted perfectly in conformity with the operation procedures.

In addition to the request for ARPs corresponding to alarms, we have provided also functions to proceed to one-push request for the emergency operation procedures which may be required next when the accident countermeasures would have to be faced in place of the alarm response. Such support information can be afforded as a part of integrated manual, covering all along the countermeasure process even if the failure should develop into an accident.

6.4 Confirmation of Reset

In order to proceed to confirmation of reset after successful completion of the corresponding countermeasures, we have provided specially a reset alarm display.

7. ALARM DISPLAY SYSTEM

In accordance with the above-mentioned design principle, we have established the alarm display system described below.

(a) Alarms on the large overview display

- With a view to taking an efficient advantage of the large overview display, alarms are shown, making use of its great features of continuous display and of location aided information.

- Integrated display of the plant flow diagram and the alarms, for easier instinctive recognition of alarm location and plant status.

- Display of all the alarms by hierarchical classification according to their priority.

  a. Important alarms are shown individually with a partly adjustable display for easier recognition.

  b. The other alarms are displayed by group alarms, of which the precise identification can be made on a CRT in a hierarchical process.

- Visual confirmation of the alarms according to their priority.

  a. Important alarms are located on the upper part of the display, with the most important ones on the top. Size of the characters is optimized in consideration of their readability. First Out (F.O.) alarm is indicated on the top of the display in large characters.

  b. The alarms other than F.O. are displayed in admissibly small characters, considering that the volume of the displayed information and the size of the characters are in relation of trade-off and that the operators are expected to comprehend its content, thanks to the fixed location display.

(b) CRT alarms available at the operation console

- For the purpose of easier alarm recognition and their management, the alarms are categorized into 4 groups according to plant system and their priority, i.e., 2 groups of the primary system, each group of turbine system and electric system.

- With the dynamic suppression of alarms and the unification of the alarm messages, the number of alarms is reduced in a range where the operators can recognize them easily (about 10 alarms for each group).

(c) Combination of the large overview display and CRTs

- For the purpose of operating the displays together in the most appropriate way, the entries and the paths are designed in a flexible way so that they can be used in a way as it may be judged good by the operators depending upon the situation.

(d) Provision of ARPs

- For the purpose of making sure that the appropriate countermeasures should be taken further to the alarm, we integrated the alarm response procedures into the computer software. We took into consideration easy revision management of the procedures (prevention of double management of the data base) and maintenance of the conformity of the procedures. In this meaning, we adopted the basic principle of direct procedures display and of unified data base management.

(e) Coding of the alarm sounds

- We have set coding of the alarm sounds with their frequency and the length of their repetition period, according to the systems concerned and the category of the alarms such as F.O.

8. DISPLAY METHOD OF ALARM

Optimization of the alarm colors must be made in such a way to prevent that the alarm should be overlooked. For this reason, it is evident that highly eye-catching colors which are distinctly discernible from each other must be chosen. Also we must avoid the colors which would cause visual fatigue of the operators who keep watching for a long time.

For these reasons, we have chosen gray back-ground taking account of harmony with the conventional alarm colors and operators' familiarity with some colors used for a long time. The selected three colors are as follows:

(a) Alarms which require operators' response: red
(b) Alarms which require operators' confirmation due to the interlock system actuation etc. to the alarm: yellow
(c) The other alarms prioritized by the preceding alarms ((a) and (b)): green

The new alarm system CRT screen is shown in Figure 2.

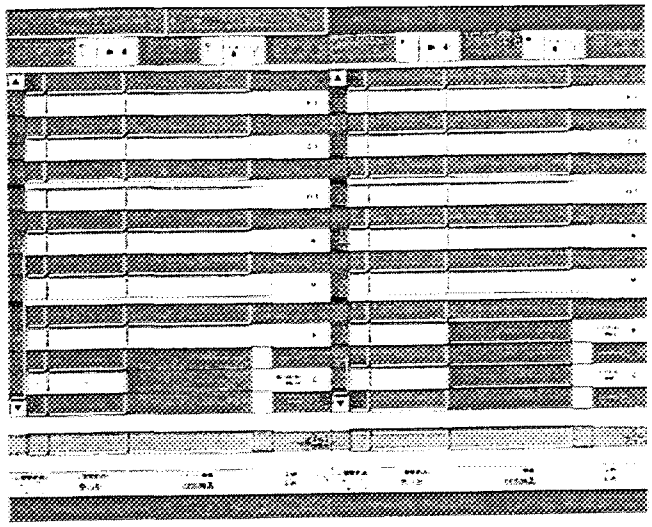


Figure 2: Display Format of New Advanced Alarm System

9. STATIC VALIDATION AND REFLECTED ITEMS

Based upon the specifications established at the design room level, a mock-up was made for the operators' evaluation.

10. PROTOTYPE SYSTEM FOR VALIDATION OF THE FUNCTIONS

We have built a prototype system in order to validate NAS throughout dynamic simulated operation. The characteristics of the prototype are described hereunder. The prototype system consisted of a large overview display, CRTs and AMCB, necessary for NAS. It was coupled with a full scope simulator which simulated a Japanese standard 4 loop plant.

Validation installations built for the above purpose are described in Figure 3.

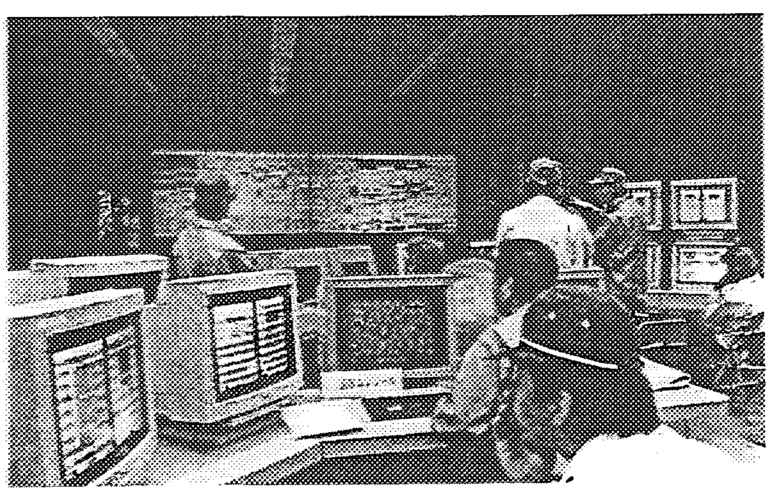


Figure 3: Prototype System for Validation Test

11. DYNAMIC VALIDATION TEST AND THE IMPROVED ITEMS

11.1 Validation Method

Since the newly developed system leads to substantial improvements of alarm recognition process and of the monitoring operation sequence such as the procedures to shift to the monitoring operation, wide range evaluation works, inclusive of the operators' subjective evaluation and quantitative evaluation of the operability with NAS, have been required. For this purpose, we have conducted the following validations.

(a) Validation of the user's acceptance

We have made a questionnaire to the operators in order to verify if they had felt that NAS was easily operable and if the basic specifications had been considered acceptable by them subjectively.

(b) Validation of the system performances

In order to verify if the newly developed alarm system fulfills the expected improvements as compared with the conventional systems in performing the tasks of recognition, confirmation and treatment, we have conducted the following variation works and confirmed that the designed performances are attained quantitatively and that the intended improvements are proven.

- Number of alarms transmitted and the suppression rate
- Request sequence of the related information

(c) Validation of the operators' performances

In order to verify if operators performances in carrying out the necessary measures are improved further to the improved performances of the alarm system itself, inclusive of the higher secondary failure detection rate, we have conducted validation on the following items.

- Detection time of secondary failure
- Utilization rate of the alarms
- Work load reduction rate(NASA-TLX method)

11.2 Results of the Validation Test

Dynamic operation validation with simulator confirmed the improvement effects as compared with the conventional alarm system. On the other hand, with regard to the subjects on which the operators made valuable comments, we have established improvement scheme which shall be integrated in the final specifications of NAS.

(a) The user's acceptance

The results of the questionnaire are shown in TABLE I. It was confirmed that NAS had been accepted by the users.

Table 1: Results of User Questionnaire

Alarm Confirmation Process	Improvement Items	Rate of "Effective/Rather Effective"
Detection Recognition	Large Overview Display	Alarm Detection on LOD 100% Total Plant View 75%
	Simplification of Confirmation Process through Group Alarm (Large Overview Display)/Individual Alarm (CRT)	Grouping in accordance with Importance 70%
Confirmation	CRT	Alarm Detection from Alarm CRT 100%
	Facilitation of Secondary Malfunction Detection	Secondary Malfunction Detection with 'OK Monitor' 95%
	Facilitation of Transition to Monitoring/Operation	Operation CRT Request 100% ARPs Request 100% (Single ANN)
Corrective Action	CRT	
	Display Format	Improvement of Visibility 66% (Positive Display, Half-tone)

(b) The system performances

- Number of alarm activation and prioritization rate

We confirmed that the number of alarm activations was within 1 page for every group, mostly under 10 activations.

Also, we are now sure that an adequate unification of the alarms will allow to further decrease the number of alarms.

As a conclusion, the objectives of our design are achieved.

The prioritization rate has been improved compared with that of the conventional system further to the enlarged application range of the alarm prioritization logic. Number of activated alarm is described in Figure 4.

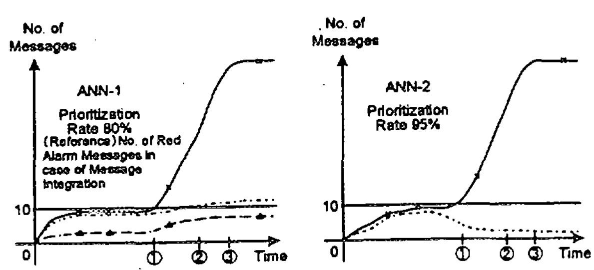


Figure 4: Number of Alarm and Suppression Rate

- Request sequence

Validation of the real information response time during the operation allowed to confirm that the shift to the monitoring operation from the alarm is made smoothly. High efficiency was proved through analysis of the request sequence based upon the operation log and the evaluation by the operators answering to our questionnaire. Variation results are shown in TABLE II and TABLE III.

Table 2: Related Information Request Function Utilization Rate

Malfunction	Alarm	Rate of design base request sequence
1. B.O	Charging pump auto start-up failure	70%
2. Reactor Trip	Two rods stuck at the Reactor trip	80%
3. PSS failure	PSS failure	50%
4. RCP failure	RCP stand pipe water level high	70%

Table 3: Alarm Response Procedures Utilization Rate

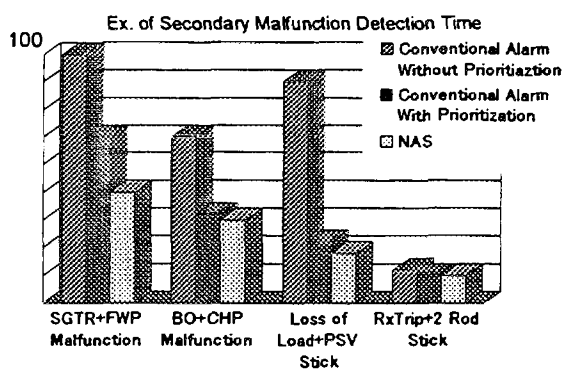
malfunction	Operator	Shift-supervisor
Single alarm event	100%	100%
Multiple alarm event	29%	53%

(c) Operators' performances

- Detection of secondary failure

During the dynamic validation, in addition to the basic event such as SGTR and BO etc., we have simulated secondary failures such as defective isolation of the feed water, etc. and we measured detection time by the operators. As a result, we confirmed a shorter detection time compared with the conventional system. It proves that we can expect to carry out very rapidly and surely the necessary operations. Validation results are shown in TABLE IV.

TABLE 4: Detection Time of Secondary Failure



a. Secondary Malfunction Detection Time	Approx.20% Reduction
b. Secondary Malfunction Detection Time Variation	Approx.20% Reduction
c. Alarm Usage Rate	Multiplied 1.7-fold

- Work load reduction rate (by NASA-TLX method)

  By means of the NASA-TLX method, we tried to evaluate the work load and to determine, by relative comparison with the conventional alarm system, reduction rate of the work load. As a result, we confirmed that the total work load had been lower. Validation results are shown in TABLE V.

Table 5: Reduction Rate of Operator's Workload

	Conventional Alarm System	New Advanced Alarm System
WWL	63.7	47.0
WWL Reduction	26% Reduction	

WWL: Weighted Work Load

12. CONCLUSION

We introduced in this paper the history of the development and application of the alarm system in Japanese PWR plant, and the development of NAS together with the validation results as the results of our latest development.

Since the alarm system performs important functions for the security and stable operation of the plant, we continue to integrate the results of our development into the commercial plants and to pursue improvement.