Technical Improvement and Maintainability Upgrade of PWR Instrumentation and Control Systems

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The digital control technology has been applied step by step to the recent PWR instrumentation and control (I & C) systems, and also it is planned to apply it to all the I & C systems, including the safety grade systems related to the reactor safety for the Advanced PWR plant. The integrated digital I & C systems have also been updated to enhance the maintenance capabilities of the systems, to optimize maintenance activities and reduce workloads of maintenance personnel. As a result, the integrated digital I & C systems have been established which can be applied to the actual plants, and which can contribute to the enhancement of reliability, hardware reductions and maintenance workload reduction of about 20% in comparison with the latest plants.

1. Introduction

Instrumentation and Control (I & C) systems for nuclear power plants have been technically improved based on well-established thermal power plant I & C systems and taking requirements for high-grade safety and reliability which are peculiar to nuclear power plants into consideration. In recent years, considerable progress has been accomplished in improving and developing nuclear power plant I & C systems through the introduction of remarkably advanced electronic equipment technology in order to meet new demands for operability and maintainability.

This paper summarizes the results of upgrading maintainability research on the integrated digital I & C systems, focusing on digital system technology which has already been partly applied in the latest pressurized water reactors (PWR) in operation or which is being planned to fully apply in Advanced PWRs (APWR), also considering the merits of digitalization, the history of development, applications for actual plants. The purpose of the research for the integrated digital I & C systems is to realize further improvements in the maintainability of I & C systems including the reactor and turbine generator systems.

2. Trends of digitalization

2.1 Development and history of digital systems

From early on, analog modules and electromagnetic relays had been used for PWR I & C systems and well-established technologies had been applied to them. Since the 1980's, digital technology has been gradually introduced into plants, starting with auxiliary systems such as radioactive waste processing systems. In the 1990's digital I & C systems have been fully applied to non-safety grade systems including the reactor control systems in Ohi Nuclear Power Station Unit Nos. 3 and 4. Moreover, plans are being made to adopt the integrated digital I & C systems in APWRs in which all systems including safety grade systems are digitalized. Consideration is also being given to having previous plants change their I & C systems to digital systems in turn.

Features of digital I & C systems which have been developed include:

- Improvements in the reliability and the availability of plants thanks to its redundant architecture and self-diagnostic function (The evaluated result of the mean time between failures of each control system is about 100 years or more.);
- Improvements in the operability of plants due to the enhancement of automatization and improvements in control and monitoring function; and
- Improvements in their maintainability as a result of the automatization of periodic tests of I & C systems and the enhancement of their self-diagnostic functions.

Moreover, such I & C systems contribute to improvements in plant economy (reductions in the amount of hardware needed and construction costs) through the establishment of systems which actively utilize computer technology and multiplexed data transmission.

2.2 Integrated digital I & C systems

Plans are being made to apply the integrated digital I & C systems in APWRs. These systems have been developed incorporating the operating experience of digital technology introduced into recent plants together with the latest results of various researches. In these systems, digital technology is introduced into safety as well as non-safety grade systems. These systems are connected with advanced main control boards equipped with CRTs, FDPs (flat display panel), and touch screens for fundamental software operation through multiplexed data transmission. In this way the merits of digital technology such as high reliability and maintainability are exploited most efficiently. Thanks to these features, it becomes possible to further improve the reliability, operability, maintainability, testability and economy of plants.

Fig. 1 shows the system architecture of the integrated digital I & C systems. They are outlined as follows.

(1) The system is hierarchized, and its redundant as well as distributed architecture is properly realized at every hierarchical level in response to requirements in terms of both safety and availability of the plant.

(2) Touch-operation is fully applied to the operation of the system from the main control board, and optical data transmission is fully employed for signal transmission to local logic cabinets which control individual components. **Fig. 2** shows a conceptual figure of the main control room in APWR.

(3) The maintainability of the plant is improved as a result of the maintenance support provided by the system which exploits features of digitalization such as the expansion of the scope of self-diagnosis, the centralized management of maintenance information, and the presentation of mainte-

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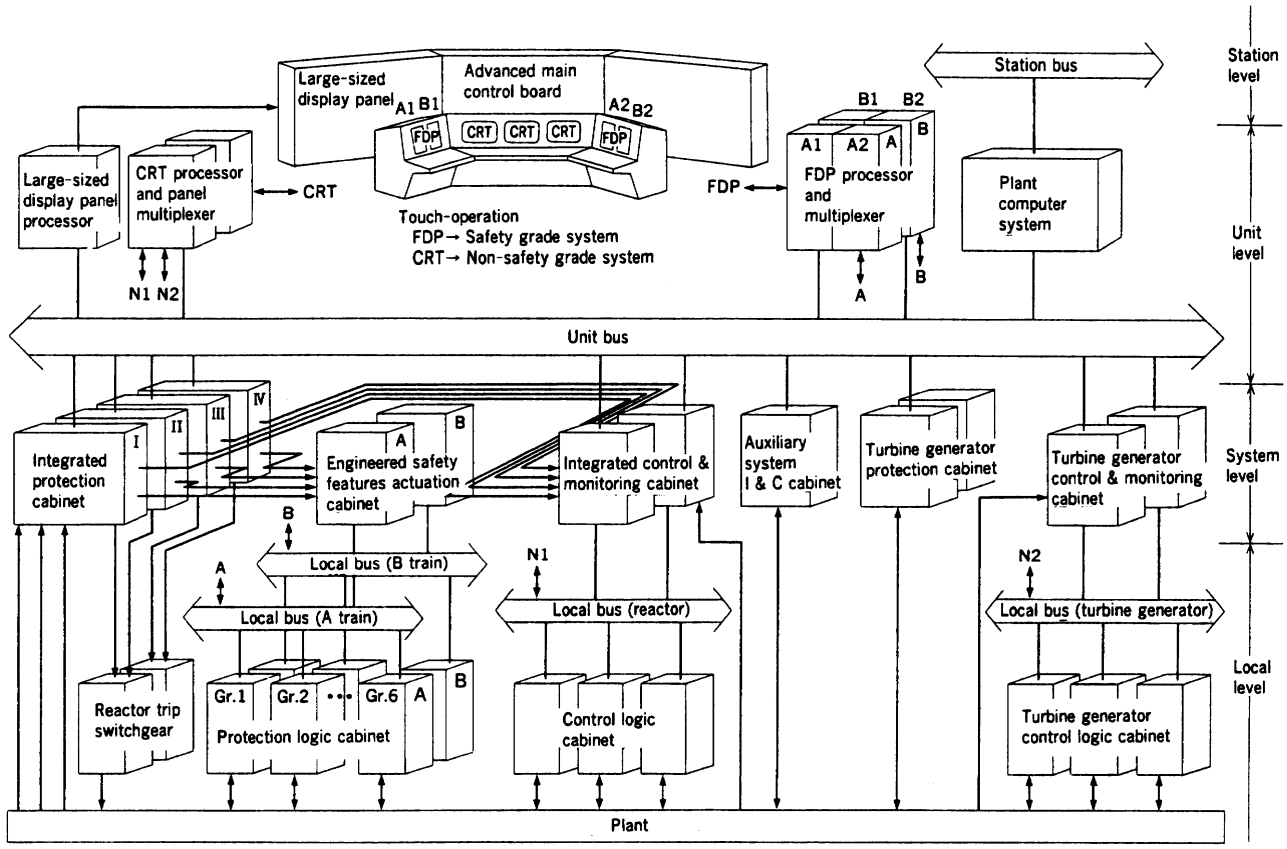

Fig. 1 System architecture of overall digitalized I & C system
The figure shows the system architecture of the integrated digital I & C systems.

nance procedures.

Consideration is being given to uniting and integrating similar systems into the system architecture including those for the reactor, turbine generator, and electrical systems.

Thanks to the unification of various types of control systems through digitalization and the reasonable function-based distribution which becomes possible due to the enhanced flexibility of interfaces among different systems, a well-balanced system architecture has been realized which integrates cabinets with similar functions at the same area at every hierarchical level.

3. Maintainability upgrading of integrated digital I & C systems

3.1 Purpose of maintainability upgrading

One of the purposes of digitalization is to improve maintainability, and the fundamental architecture of the integrated digital I & C systems have been established for the aforementioned circumstances. Furthermore, the said systems have been examined with the aim of realizing well-balanced plants as a whole through upgrading from the perspective of its application to actual plants and maintainability, i.e. the optimization of the method of maintenance. The goals of research into upgrading maintainability for the integrated digital I & C systems have been as follows.

- Reductions in maintenance workloads

  To reduce the amount of maintenance work by taking advantage of the merits of digitalization for the purpose of reducing the workload of maintenance personnel.

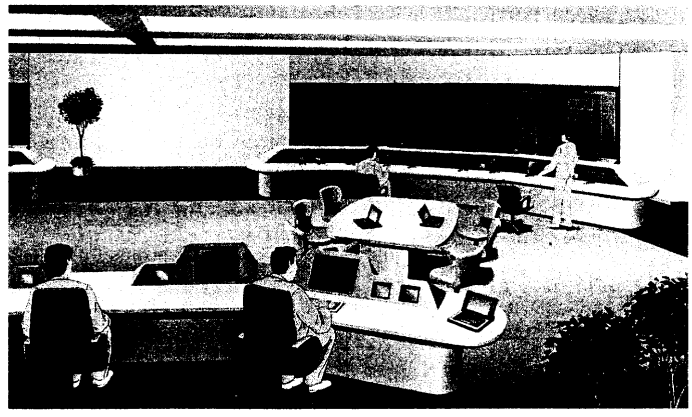

Fig. 2 Conceptual figure of main control room in Advanced PWR

- Upkeep of system reliability

  To consider how to realize a well-balanced system while maintaining inherent system reliability when reducing workloads.

- Relaxation of stress on maintenance personnel during maintenance and repair work

  To alleviate tension or stress on maintenance personnel as much as possible during maintenance and repair work such as isolation and preservation for maintenance that could possibly influence plants. In addition, to consider how to avoid increasing mental loads on maintenance personnel due to the increased complexity of maintenance work as a result of digitalization.

- Centralized management of information and facilitation of its future effective utilization

  To promote centralized management through the concentration of information, since it is felt that the transmission of various types of information regarding maintenance become easier to handle and that the effective utilization of such information contributes to the further upgrading of maintainability.

3.2 Maintainability upgrading and establishment of overall system architecture

3.2.1 Functions required for upgrading maintainability

Functions required to upgrade maintainability have been selected by analyzing details of present maintenance work for various kinds of I & C systems and evaluating their needs, in cooperation with electric power companies. The main points are shown below.

(1) Coping with faults

Fault information and operational guidance are displayed on the CRT for maintenance and repair whenever failures or other problems occur.

(2) Maintenance work

I & C systems are such that plant monitoring parameters can be confirmed on a maintenance console (in main control room) and on local areas, and necessary work including remote input can be performed during testing. Maintenance work is facilitated through the mitigation of the concentration of workload on the main control board during periodic maintenance.

(3) On-line self-diagnostic information

Materialization of overall self-diagnosis is achieved by making local detectors intelligent, and batch processing and management of diagnostic information including the automatic evaluation for the degree of significance and effect.

(4) Periodic maintenance

Expansion of the scope of self-diagnosis, enhancement of the simplification and automatization of tests, review of the scope of tests, and other functions are performed as a part of periodic maintenance.

(5) Maintenance of facilities

The maintenance of plant facilities is enhanced through the functions of identifying trouble positions, simplification of isolation and the preservation maintenance work.

3.2.2 Establishment of overall system architecture

System architecture has been examined from the following viewpoints, and the overall architecture of the integrated digital I & C systems for APWRs, into which upgraded maintainability is incorporated, has been established.

- Investigation into the amount and extent of maintenance work for the plant monitored and controlled in the main control room over a given period of time.
- Examination of information transmission methods
- Estimation of information transmission loads
- Proposal of software V & V (verification and validation) methods
- Estimation of the amount of hardware

The investigation of the concentration of maintenance workload in the main control room consists of examining the current state of the previous plant having the shortest periodic maintenance time. The concentration of maintenance workload on the advanced main control board has been estimated on the basis of the results of the above-mentioned investigation, and examination has been made on the number and arrangement of CRTs and FDPs including the specifications of the maintenance console.

On the other hand, a maintenance computer system has been prepared to collectively manage the self-diagnostic information of every I & C system and to supply maintenance support information based on detailed fault information. Information transmission methods have been examined and information transmission loads have been estimated using this computer. In this way, the integrated digital I & C systems have been optimized.

Fig. 3 shows an outline of the maintenance computer system.

The maintenance system for the I & C system has been established with the maintenance computer system at the hub. In order to apply this system to actual plants, it is being planned to develop the computer system and software to be capable of maintaining the entire plant by linking it with the component maintenance management system, which supports system isolation as well as maintenance and management of machinery and equipment, together with the component status monitoring and diagnostic system, etc.

The software V & V of the I & C system associated with the main control board has also been examined, and it has been decided to create software architecture which easily conducts V & V, keeping in harmony with the characteristics of the man-machine interface.

As a result of the estimation of the amount of hardware required, the number of CRT processors and safety grade system cabinets has slightly increased. However, the amount of hardware has decreased for the plant as a whole compared with the latest plant in operation, and the integrated digital I & C systems have been functionally improved.

Finally, a prototype integrated digital I & C system has been manufactured and its functions have been verified. As a result, it has been confirmed that its fundamental system architecture is appropriate and effective.

3.2.3 Evaluation of effect on workload reduction

The effect of the established overall system architecture of the integrated digital I & C systems on workload reduction at the time of the periodic maintenance and system troubles has been evaluated.

The results of this evaluation have shown that maintenance workloads at the time of periodic maintenance are reduced to about 80% of that of the latest plant in operation for main control systems. In order to reduce this further, it is also necessary to improve maintenance instructions for detectors, on which maintenance work is done during periodic maintenance, when the integrated digital I & C systems are applied to actual plants.

The results of this evaluation have also shown that workloads at the time of system problems or faults are reduced. Isolation and preservation work for maintenance which is particularly complicated and the great degree of skill needed have been sufficiently reduced by narrowing the scope of system units to be isolated.

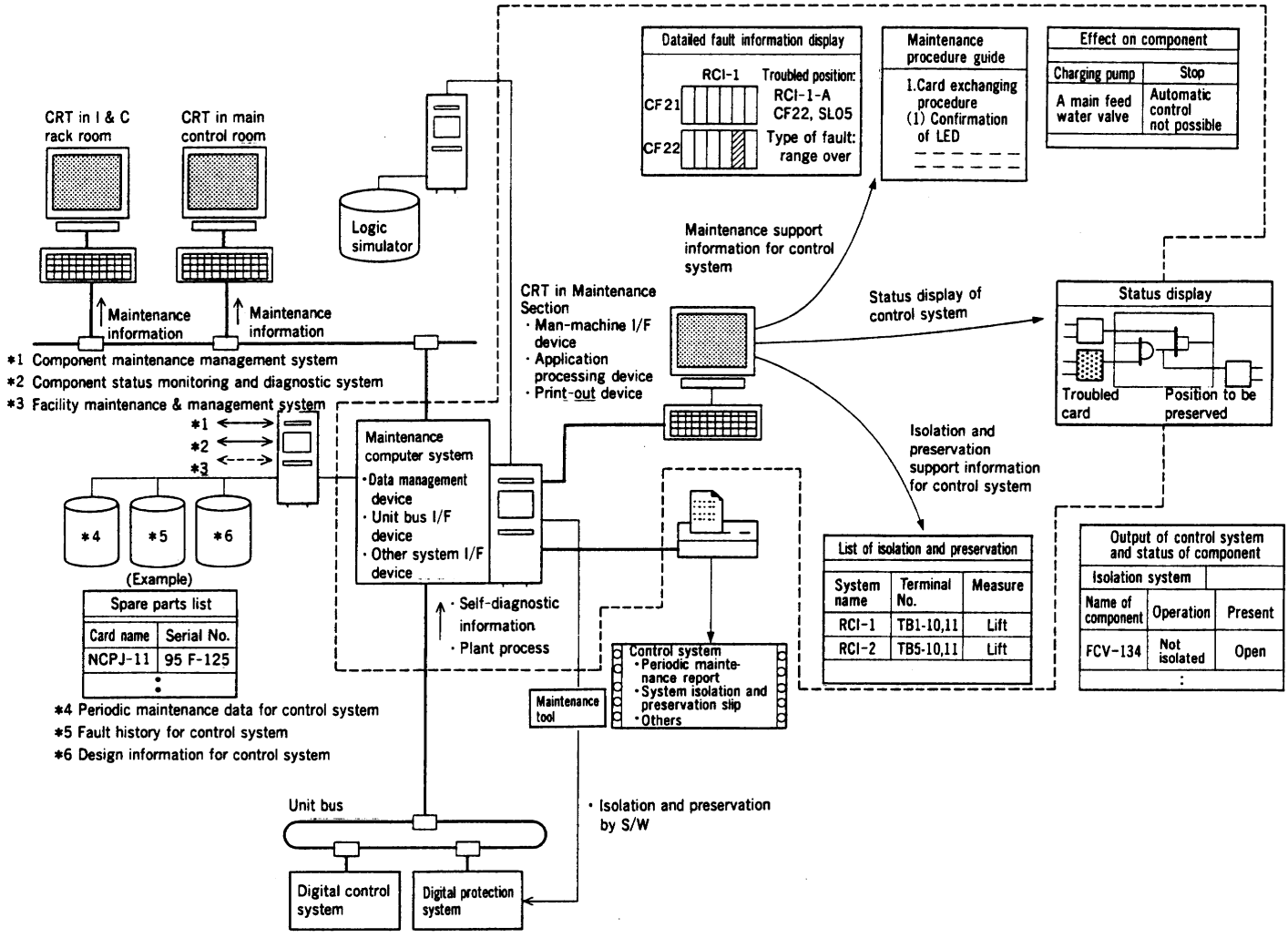

Fig. 3 Outline of maintenance computer system
Maintenance computer system managing maintenance information is outlined.

3.3 Comprehensive evaluation of maintainability upgrading of integrated digital I & C systems

A point of the system subject to modification as a result of research into upgrading maintainability is the connection of the maintenance computer system. The reliability, operability, maintainability, and the amount of hardware of the plant have been evaluated and compared with that of previous plants and the latest plants in operation on the basis of the final system architecture. **Fig. 4** outlines the results of this comprehensive evaluation.

Results obtained with the plant equipped with the integrated digital I & C systems are presented below.

(1) Reliability

Plant reliability has been improved further compared with that of the latest plants in operation thanks to the reliable safety actions and improvements achieved in the availability of the system.

(2) Operability

Misoperation has been reduced and mental workloads have been eased compared with that of the latest plants in operation. Walk-through of operators have almost reduced.

(3) Maintainability

Evaluation results have shown that the number of spare parts are decreased by about half and the amount of maintenance work required for the main systems is reduced by about 20% compared with that of the latest plants in operation. Also faults and trouble positions can be detected self-diagnostically.

(4) Amount of hardware

The amount of hardware required for the signal processing system and cable has been reduced compared with that of previous and the latest plants in operation. For the system associated with the main control board, the number of board-mounted devices has been drastically decreased and replaced with CRTs and FDPs.

4. Conclusion

The integrated digital I & C systems have been simplified and the workload for them has been reduced in terms of maintenance as a result of research into the upgrading of maintainability. For the full application of digital I & C systems to APWRs, progress in actual plant design will therefore be realized in the near future by putting the integrated digital I & C systems at the heart of plant control which has been improved in terms of reliability, operability, maintainability, and the amount of hardware required compar-

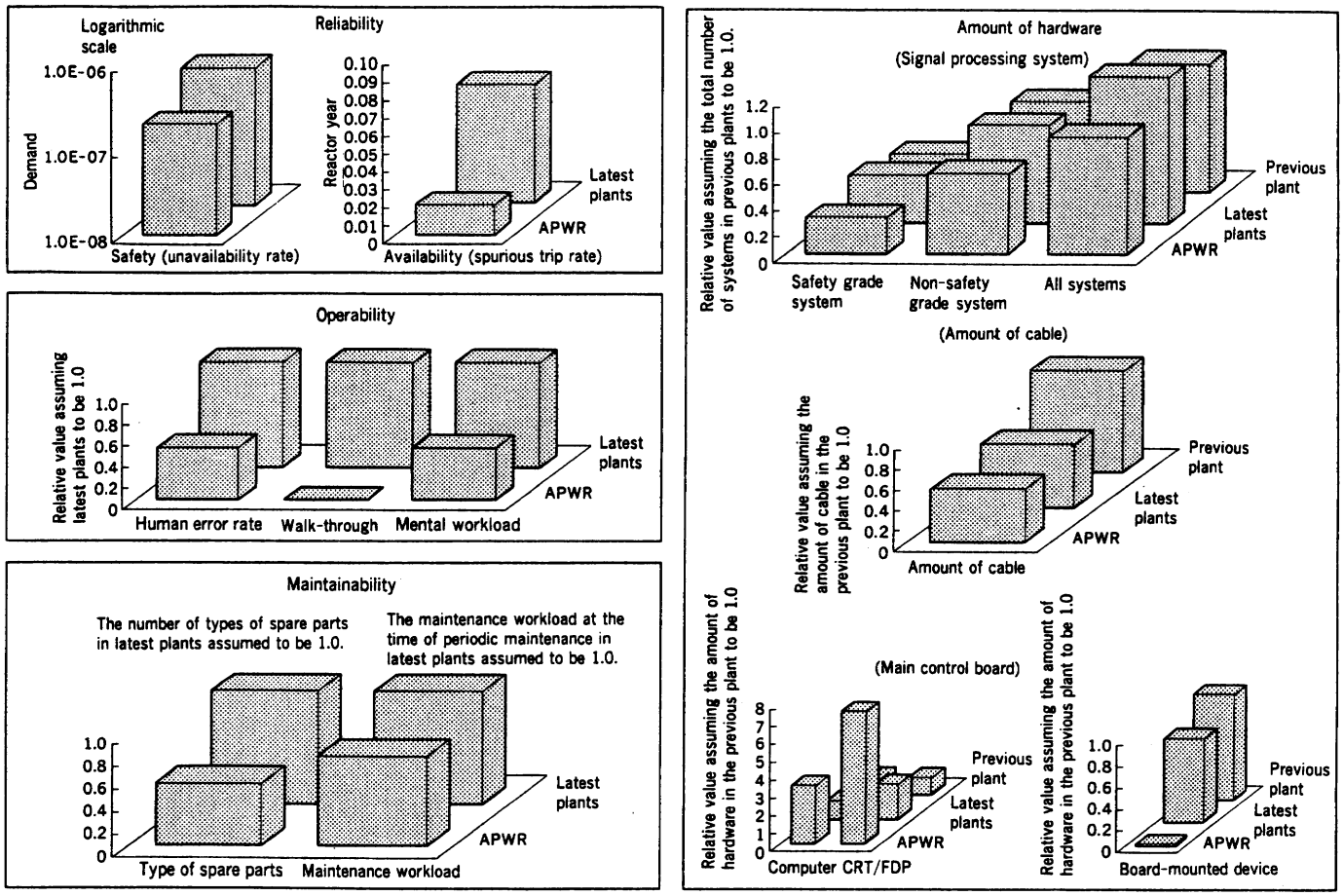

Fig. 4 Evaluation of overall digitalized I & C system
Reliability, operability, maintainability, and the amount of hardware of the integrated digital I & C system are evaluated compared with those of existing systems.

ed with those of I & C systems of the latest plants in operation.

Regarding an I & C system as the center of operation and control with the interface between man and machine, it is desirable to aim at further improvements in system functions, and greater emphasis will be placed on improvement and development in the future. This study has been conducted in cooperation with The Kansai Electric Power Co., Inc.; The Hokkaido Electric Power Co., Inc.; Shikoku Electric Power Co., Inc.; Kyushu Electric Power Co., Inc.; The Japan Atomic Power Co. and Mitsubishi Electric Corporation.

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