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IN-OPERATION INSPECTION TECHNOLOGY DEVELOPMENT <Development of a Rational Maintenance Management Method for Light-Water Reactor Plant>

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Abstract

In 1985, the Japanese national project named "In-Operation Inspection Technology Development (IOI) " was initiated, as a part of the activities for advancing the LWR(light water reactor)technology in Japan.
This project developed the techniques for in-operation monitoring and detecting of early anomalies of nuclear power equipment such as rotating machines, valves and piping. Further, the estimation systems for diagnosing and predicting a degradation rate of these items of equipment were constructed. Based on these results, a new maintenance management technology was constructed.
This paper describes the outline of the new maintenance management concept.

1. Introduction

It has been over than 30 years since the first commercial nuclear power plant entered service in Japan. Fifty-two LWR units are operating now with a high level of plant availability. On the other hand, the issue of countermeasures for plant aging becomes very important. Moreover, the nuclear power generation is required to be economically competitive.
In 1985, the Japanese government, through the Ministry of International Trade and Industries (MITI), entrusted the Japan Power Engineering & Inspection Corporation (JAPEIC) with the national project named "In-Operation Inspection Technology Development (IOI)" as a part of the activities for advancing LWR technology in Japan.
The objectives of the IOI project are to increase power plant availability by the development of inspection technologies that contribute to the expansion of running

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time and the reduction of the periodic inspection term. The IOI project consists of two phases. In Phase 1, the aim was to develop monitoring technologies using the conventional and widely used techniques to ensure early detection of degradation of equipment. In Phase 2, a predictive diagnostic technology was developed. The diagnostic technology consists of detection of degradation, estimation of the degree of degradation and estimation of residual life of the equipment in advance. so, a new framework of maintenance methodology was established. This maintenance methodology is equipment management based on the model predicting approach and the logic matrix for determining maintenance strategies for equipment.
This paper describes an outline of the new maintenance methodology.

2. Outline of the IOI project

The IOI project, the object of which was the development of inspection and monitoring techniques, started in fiscal year 1985 and was completed in fiscal year 2000. This project consisted of two phases. Table 1 shows the schedule of the IOI project.

Table1 *schedule of IOI project*

	1985 1995 2000
Phase-	Early anomaly detection
Phase-	Predictive diagnostics

In Phase 1, development of new monitoring technologies for early detection of anomalies of equipment was targeted. The subjects of this phase were rotating equipment, piping and vessel. The rotating equipment selected was Primary Loop Recirculation Pump (PLRP), Reactor Coolant Pump (RCP) and Reactor Feed Water Pump (RFP). PLRP and RCP are both vertical pumps and important in BWR and PWR, respectively. RFP represents horizontal pumps. A new condition monitoring system using a vibration analysis method was developed for the rotating equipment.
Two ultrasonic testing methods were applied for on-line monitoring of the reduction of pipe wall thickness and the detection of cracks in vessels. In both methods, the heat-resistant piezoelectric transducers and the heat-resistant Electromagnetic Acoustic Transducers (EMAT) were used. The detailed results of Phase 1 were reported elsewhere [1-2].
In Phase 2, construction of a predictive diagnostic system for degradation of rotating equipment, piping and valves was targeted.
PLRP and SWP (Sea Water Pump) were selected to represent the rotating equipment. Small-diameter piping laid in a compartment containing the main coolant system in the PWR and motor driven valve were selected to represent piping and valves, respectively.
Based on the results of Phase 1, both predictable degradation modes and the potentiality of prospective diagnostic techniques were discussed. Bearing wear and shaft crack were selected as the subjects of prospective diagnostic systems using the simulation method that was verified in Phase 1 for PLRP and SWP.

In the development of the diagnostic system for piping, two degradation modes were targeted. One was high cycle fatigue of small-diameter piping and the other was detection of leakage from piping. Selected non-contact methods for remote monitoring of piping vibration and remote detection of very small amounts of leakage were investigated, Namely Laser techniques such as the Laser Speckle Method, the Infrared Imaging Method and the Sound Method. A diagnostic system consisting of a filter and a data logger connected to a sensor head and a signal data processing unit was developed and verified with the experiments using a mockup to simulate the practical state.
a diagnostic system for the gate valve was developed, focusing on two aspects. One was degradation of consumables such as gaskets and gland packing, the other was degradation of structures such as wear of stem nuts and hanging portions of valve bodies, loosening of locking nuts and misalignment of switch settings. Weight loss and stress relaxation tests of gaskets and gland packing were performed and the degradation models for consumption articles were established. Regarding wear, thrust force experiments were executed and the relationship between thrust force and active power was established. The details of these results are shown in other papers.[3-5]
Based on the above mentioned results, a new framework of maintenance methodology, called the rational maintenance management method, was constructed. This maintenance methodology is based on the model predicting approach and the logic matrix for determining maintenance strategies for equipment.

3. Concept of rational maintenance management method

3. 1 Objectives of rational maintenance management method

At present, for nuclear power plant equipment, time-based maintenance management is mainly applied. In this management program, the margin of the overhauling interval may be excessive for certain parts. It is, therefore, desirable to develop the rational maintenance management concept based on the highly accurate and comprehensive prediction of equipment degradation.

3.2 Basic concept for the rational maintenance management method

A rational maintenance management method is based on the concept of condition-based maintenance. The characteristics of this method are that it is based on the estimation of degradation and residual life of the equipment parts, that is, the Life Estimation Analysis on Failure Mode (LEAF). It determines the most appropriate inspection and overhaul / parts replacement interval by prediction for degradation of equipment based on the on-line data gained during operation or in testing. Following four items should be covered in the rational maintenance management method.

(1) Comprehensive
The rational maintenance management method should be comprehensive. It should cover all failure and degradation modes of all the parts of which the target equipment consist.

(2) Theoretical (physical model)
Factors and mechanisms should be analyzed theoretically for all failure and degradation modes in order to establish the estimation procedure and predictive physical model. These approaches lead to realization of condition base maintenance.

(3) Predictive
The rational maintenance method should determine the inspection time and the interval to overhaul or to replace the parts in advance. A system to confirm the appropriateness of the prediction is also required.

(4) Planning oriented
The rational maintenance method should enable determination of the appropriate actions such as overhauling, replacement and adjustment for progress management for the target components. A on-line monitoring system and renewal of the database are needed.

3.3 Target equipment and degradation mode

PLRP, RCP, SWP and RFP (representative rotational machines), piping and motor-driven gate valve (each part valves) were selected for application rational maintenance management.
One of the key points of the development of the rational maintenance management method is the prediction of degradation for each part of above-mentioned equipment. Use of prediction techniques based on the physical model for degradation is a key point. The following prediction methods developed in the IOI project were used for rotating machines, piping and valves.

(1) Prediction models for bearing wear and shaft crack of rotating machines by vibration method
(2) Prediction model for high-cycle fatigue damage of small diameter piping
(3) Prediction models for gasket degradation and stem-nut wear of motor-driven valves

3.4 Basic system

Figure 1 schematically shows the basic system of rational maintenance management. Conventional maintenance programs for the equipment are determined in accordance

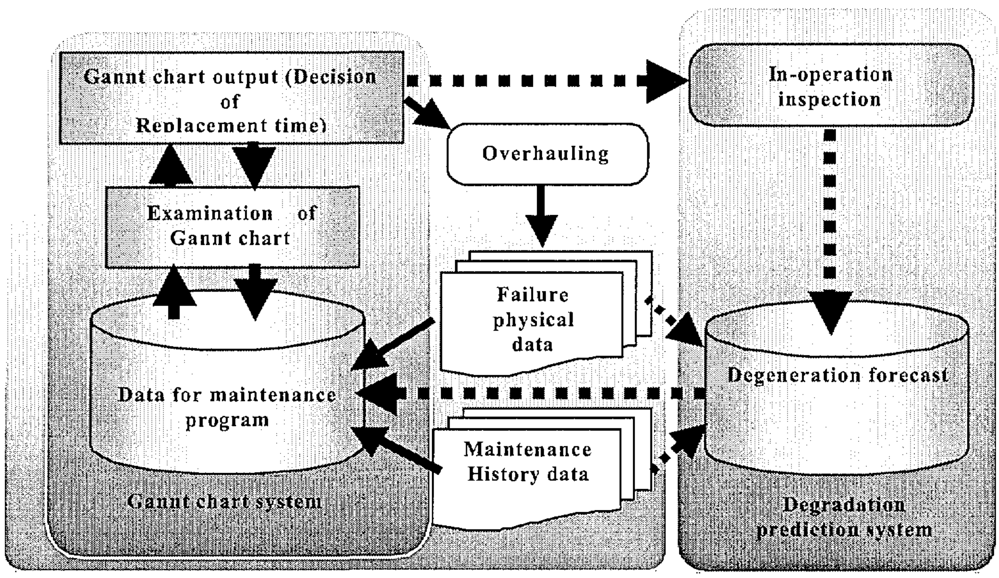

Figure 1 *Basic System of Rational Maintenance Method Preparing flow of Gannt chart using Degradation Prediction System*

with time-based maintenance. In time-based maintenance, the maintenance information are based on overhaul history, physical data of actual failure and data of similar plant. The maintenance programs were revised whenever an event occurred and the work for revising was complicated. The basic system of the rational maintenance management method produces the degradation predicting data from the on-line operation data and the maintenance database. The system finally putouts a new Gannt chart which shows the most appropriate time schedule for inspection or overhauling of the objected equipment. That enables the utility's personnel to adjust the maintenance schedule easily and in timely manner in accordance with the trends of specific parts.

3.5 Procedure for introducing rational maintenance management method

In order to introduce the rational maintenance management method, it is necessary to pursue two complementary approaches; firstry, to decide on an appropriate maintenance method for each degradation method, and secondly, to determine an appropriate inspection or overhauling interval based on the estimation of residual life for the target parts.

In order to decide on the maintenance method, it is neccesaly for to estimate the degradation modes failure initiation sequences for all the parts of which the target equipment consists. Determination of an appropriate interval for overhauling requires the consideration of the actual plant's operating schedule etc. Figure 2 shows a flow chart of the procedure for introducing the rational maintenance method schematically. The outline of the procedure is as follow,

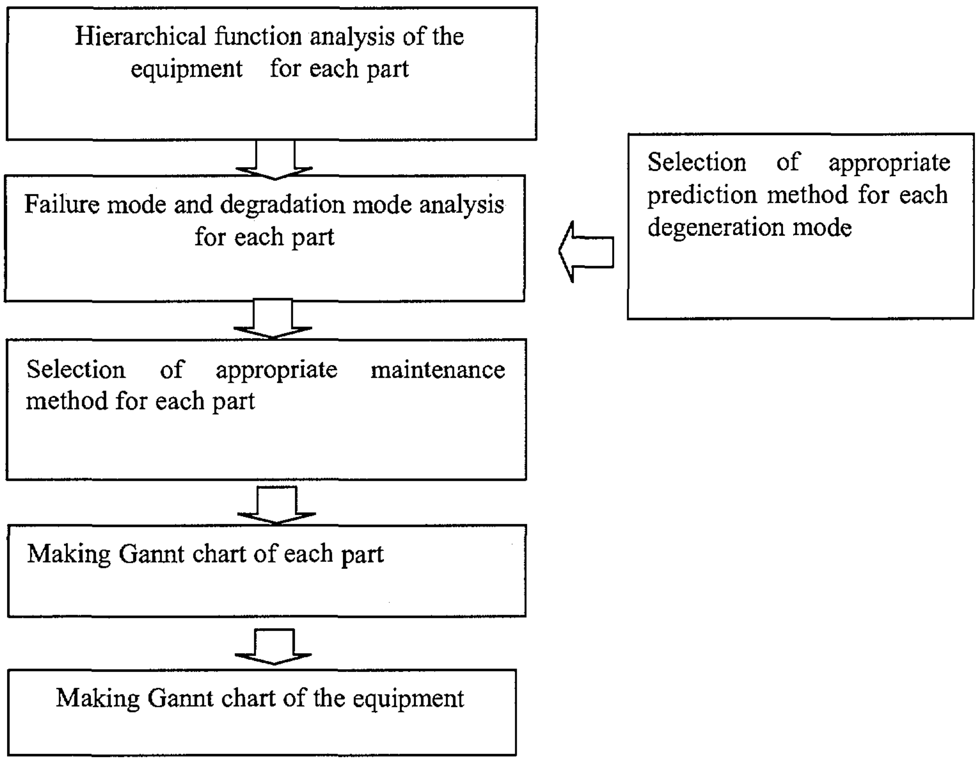

Figure2 *Introduction flow of rational maintenance management method*

(1) Hierarchical function analysis of equipment

At first, the target equipment is decomposed to the minimum parts which consist it. Then, the main functions of the equipment are subdivided into primary functions hierarchically. The relationship between each part and the functions is analyzed.

(2) Failure mode and degradation mode analysis

For all parts, assumed failure mode, degradation mode and stresses, which accelerate the degradation are listed up. Then, detection technique for failure or degradation and effective lifetime prediction methods are investigated for each degradation mode. The propriety of the selected detection technique or prediction method is examined and appropriate parameters for them are considered.

(3) Selection of the most appropriate maintenance management

The timing (in-operation, during stopping or overhauling) for sampling the above-mentioned parameters is studied and finally the appropriate maintenance management methods are determined. Figure 3 shows the classification of the maintenance management methods.

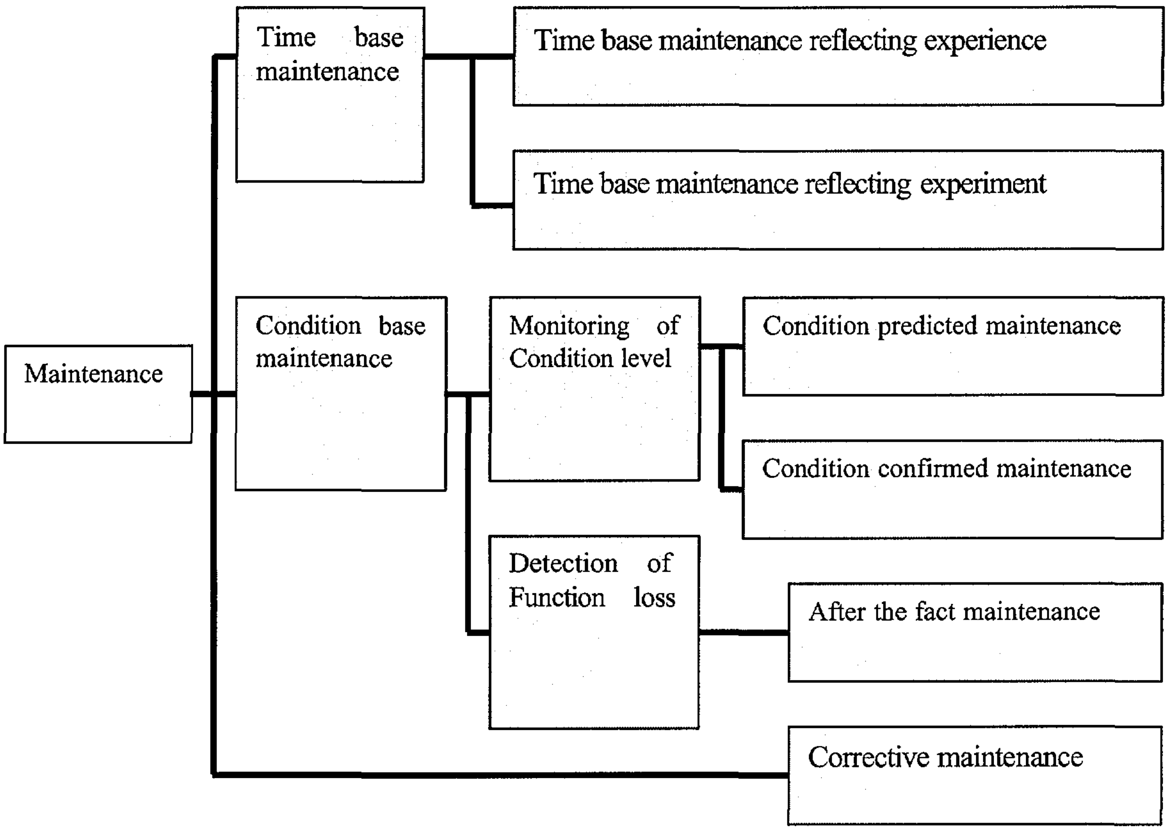

Figure 3 *Classification of maintenance by Rational maintenance management*

(4) Prediction of parts life and determination of maintenance interval
Based on the characteristics of the initiation and propagation behavior of the deterioration mode assumed for the target parts, the most appropriate methods are selected from the various maintenance methods shown in the table.
Using a database constructed by on-line data during in-operation inspection and maintenance history data, a specific maintenance interval for the target parts is determined.

(5) Determination of the most appropriate inspection time interval for parts
Based on the results obtained by (4), "Gannt chart for parts" is established.

(6) Determination of the most appropriate inspection time and interval for equipment
Selecting a critical part from the Gannt charts for parts, inspection time and interval for the equipment, "Gannt chart for equipment" are established by adjusting the schedule for the critical part.

4. Example of application of the rational maintenance management method for PLRP

Introduction of the rational maintenance management method to some equipment was tried in accordance with the procedure described above. Table 2 shows a portion of LEAF carried out for PLRP. The left column of the table shows functions analyzed for PLRP. In this table, only a portion of feed water function is shown. The feed water function is subdivided into energy transmit function, shaft support function, etc. and parts which carry out the subdivided function are listed. For each part, the results of failure mode analysis and life estimation analysis are shown. Figure 4 shows a Gannt chart constructed for PLRP based on LEAF. Revision, deletion and addition of inspection time or overhauling interval are conducted on this chart by using a personal computer.

Table2 Life estimation analysis of PLRP

function analysis	parts	failure modes analysis: failure modes	failure modes analysis: degradation modes	stress: in operation	stress: plant outage	stress: in manufacturing	life estimation analysis: subject mode	life estimation method	parameter for life estimation method	technique for measurement or monitoring	measurement period: in operation	measurement period: plant outage
	impeller	break ← crack abnormal vibration	SCC	temperature water quality stress ←		residual stress	crack	crack growth analysis	crack depth stress	NDI FEM + stress measurement		- -
							SCC	possibility analysis	water quality	water analysis	-	
			high cycle fatigue	stress repetition stress -concentration			crack	crack growth analysis	crack depth stress frequency stress amplitude	NDI pressure gauge impossible	- 	-
							fatigue	possibility analysis	stress frequency stress amplitude	pressure gauge impossible	-	
		performance deterioration ↑ impeller choking	crud deposition	water quality			performance deterioration	(performance monitoring)	flow rate ,pressure	each sensor	-	
							crud deposition	trend extrapolation	crud rate	visual inspection		-
		performance deterioration ↑ clearance enlargement ←	wearing ← rubbing erosion ← cavitation		poor accuracy assembling		performance deterioration	(performance monitoring)	flow rate ,pressure	each sensor	-	
							rubbing	(acoustic monitoring)	acoustic		-	
							erosion	extreme analysis	erosion depth	visual inspection		-
	-											
	pump shaft	shaft rupture ← crack	SCC	temperature water quality stress ←		residual stress	crack	crack growth analysis	crack depth stress	NDI/estimate with vibration FEM + stress measurement		- -
							SCC	possibility analysis	water quality	water analysis	-	
			high cycle fatigue	stress repetition stress concentration			crack	crack growth analysis	crack depth stress frequency stress amplitude	NDI/estimate with vibration shaft vibration estimate with -vibration	 - -	-
							fatigue	fatigue analysis	stress frequency stress amplitude	shaft vibration estimate with -vibration	- -	
			thermal fatigue	thermal fluctuation			crack	crack growth analysis	crack depth fluctuation amplitude fluctuation frequency	NDI/estimate with vibration test data/flow analysis test data/flow analysis		-
							thermal fatigue	possibility analysis	fluctuation amplitude fluctuation frequency	test data/flow analysis test data/flow analysis		
		abnormal vibration ↑ bending ←	thermal stress	thermal distribution		residual stress	bending	(vibration monitoring)	shaft vibration	vibration sensor	-	
	:											
function	guide bearing	abnormal vibration ↑ support deterioration ↑ clearance enlargement	wearing freaking ← fatigue	vibration bearing force bearing force			clearance enlargement	trend extrapolation	wearing depth	surface inspection		-
							wearing	wear growth analysis	bearing force	estimated from vibration	-	
							fatigue	fatigue analysis	frequency	motor vibration	-	
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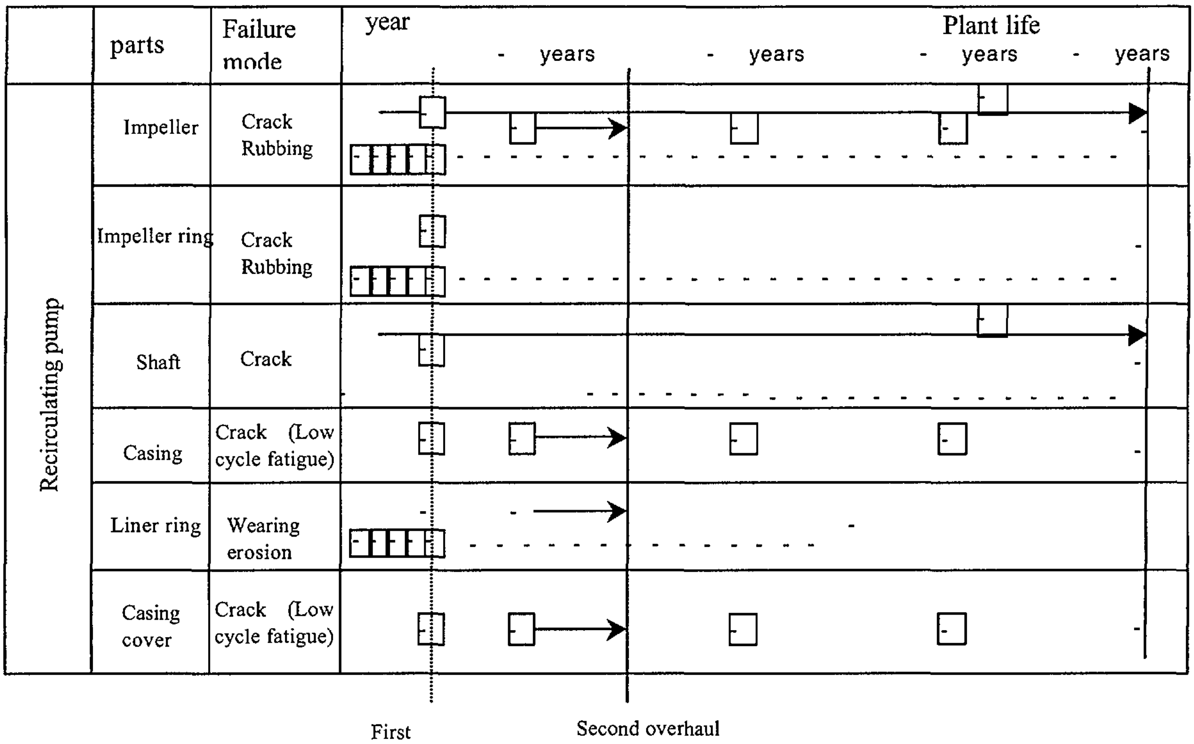

- - time-base maintenance reflecting experience
- - time-base maintenance reflecting experiment
- - condition predicted maintenance(in -operation)
- - condition predicted maintenance(plant outage)
- - condition predicted maintenance(during overhauling -
- - condition confirmed maintenance(in -operation -

(In case of continuous monitoring)

- - condition confirmed maintenance(plant outage -
- - condition confirmed maintenance(during overhauling -
- : Estimated life

Figure 4 *Gannt chart for PLRP*

5. Evaluation of advantages and problems of application to actual nuclear power plant equipment

5.1 Advantages

Advantages of application of the rational maintenance management method to actual plant equipment were evaluated in the case of rotational machine, piping system and valves. It enables optimization of the maintenance management program by means of a comprehensive, theoretical, predictive and planning-oriented concept and reduction of the maintenance cost for PLRP and valves.

5.2 Problems

Investigation of life prediction models and techniques revealed that useful quantitative data on the actual equipment or parts to estimate their residual life are relatively scarce. Therefore, it is necessary to substantiate the database for the life prediction and to improve the accuracy of the prediction. In order to expand the application of the rational maintenance management method to other equipment, grouping of the objected equipment and standardizing of the database are needed.

6. Concluding remarks

A long-term Japanese national project, In-Operation Inspection Technology Development has completed. A new maintenance management methodology named rational maintenance management method was constructed. This method introduces the concept of condition-based maintenance management to the conventional time-based maintenance management for nuclear power plant. Future expansion of application field of the new maintenance management method is expected.

REFERENCES

[1] M. Sugiyama, I. Hasegawa, H. Kitahara, E.O'Shima, Takada; Development of Diagnosis System for Primary Loop Recirculation Pump Anomaly Quantative Estimation, ICONE-3 (1995)

[2] O. Tsuneoka, I. Hasegawa, H. Kitahara, C. Yasuda, E. O'Shima; Development of Diagnostic System for Reactor Coolant Pump, ICONE-4 (1996)

[3] K. Osaki, Y. Yatanabe. Y. Kitajima, H. Hattori, Y. Uhara, T. Miyoshi, E. O'Shima ; Development of Degradation Prediction Technology for Rotating Machines, ICONE-7 (1999)

[4] K. Takeshima, T. Miyoshi, E. O'Shima; Research and Development of In-Operation Inspection of Motor Operated Valves, ICONE-7 (1999)

[5] S. Doi, Y. Nekomoto, T. Miyoshi, E. O'Shima; Development of High Cycle Vibration Fatigue Diagnostic System with Non-Contact Vibration Sensing, ICONE-7 (1999)