Plant Life Management and Maintenance Technologies for Nuclear Power Plants

Tsukasa Ikegami
Takao Shimura
Masahiro Koike

OVERVIEW: In Japan, nuclear power provides one-third of the electric power used by the country and is consequently an important source of energy. To achieve efficient business operations in the electric power industry, the cost efficiency of nuclear power must therefore be improved. In addition, to ensure a steady supply of energy at a time when plans for constructing nuclear power plants are being postponed, plants that are currently operating must be able to continue stable operations over the long term. For these reasons, the Ministry of Economy, Trade and Industry, utility companies, scientists and engineers from academia and industry, and manufacturers are combining forces to develop technologies to deal with age-related degradation in nuclear power plants. Hitachi, Ltd. has been constructing nuclear power plants and maintaining operating plants for many years, and is applying the know-how accumulated through these experiences to the development of new technologies to make currently operating plants capable of operating over the long term in a stable and highly reliable manner. In this report, we survey inspection technologies, preventive maintenance, and repair/replacement technologies developed by Hitachi.

INTRODUCTION

IN Japan, nuclear power has come to occupy an important position in the supply of electric power—in fiscal year 1999, 35% of the electric power generated in Japan came from nuclear power plants.

In addition to providing a stable supply of electric power, nuclear power plants are called upon to reduce the cost of generating that power. In this regard, important issues in a maintenance plan for an operating plant are (1) stable and continuous operation, (2) cost reductions in operation and maintenance (O&M), and (3) improved facility reliability. In Japan, nuclear power plants that reach 30 years of operation must undergo a technical evaluation of age-related degradation (fitness and earthquake-resistance evaluation of all plant facilities), and based on the results obtained, establish a maintenance plan for the years ahead. Such a maintenance plan must consider cost efficiency and reliability as well as the particular circumstances of the plant in question. After 30 years of operation, plant inspections are to be carried out as needed according to this maintenance plan based on the technical evaluation of age-related degradation.

A maintenance plan established after 30 years of plant operation is then revised every 10 years. Needed repairs and preventive maintenance are carried out systematically according to this maintenance plan.

The following describes inspection technologies for age-related degradation and technical developments in repair and replacement work at Hitachi.

AGED PLANT ISSUES AND MANAGEMENT

Among the boiling water reactors (BWR) now operating in Japan, 11 have been operating for 20 years or more as of November 2000. This number will almost double to 19 by 2010 (Fig. 1). To achieve a stable supply of power and improve the cost efficiency of generating electricity in the years to come, technologies that can make these aged plants operate for an extended period of time are indispensable.

To improve the reliability and facility utilization ratio of nuclear power plants, Hitachi is engaged in the development of new technologies relating to the prevention of equipment deterioration and the maintenance of equipment in general, and in the digitization of inspection data through the introduction of information technology (IT). Hitachi is also developing base technologies required for plant maintenance related, for example, to material integrity, water chemistry control, and occupational radiation

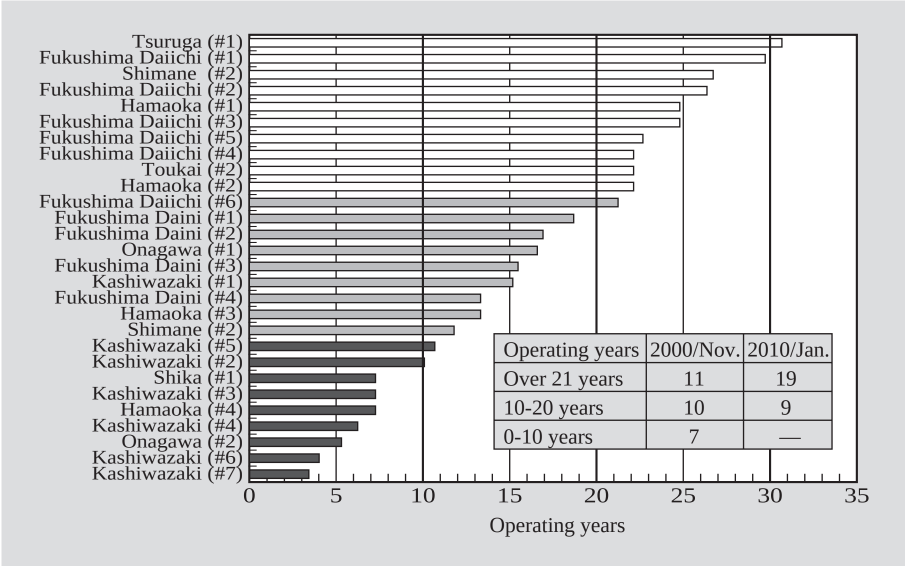


Fig. 1— Number of Operating Years for BWR Power Plants in Japan.
Among BWR power plants now operating in Japan, the number of plants that have been operating for 20 years or more was 11 as of November 2000. This number will almost double to 19 by 2010.

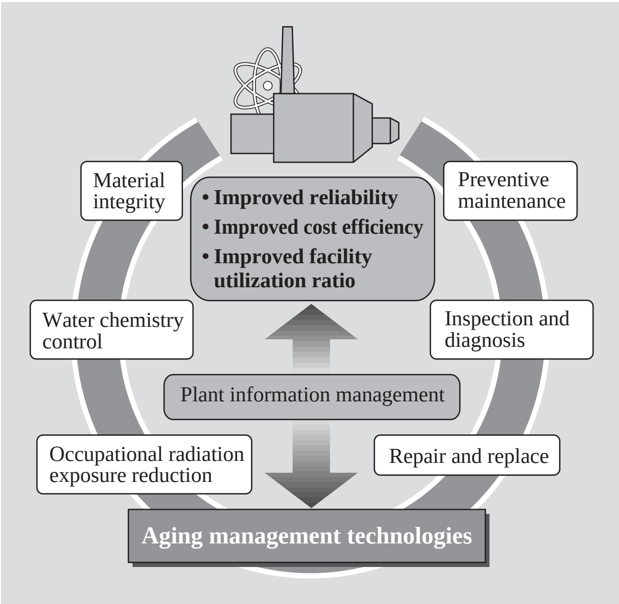


Fig. 2— Aging Management Technologies.
To improve reliability and cost efficiency of nuclear power plants, Hitachi is developing base technologies related to material integrity, water chemistry control, and occupational radiation exposure reduction, and aging-management technologies related to preventive maintenance, inspection, repairing and replacing, etc.

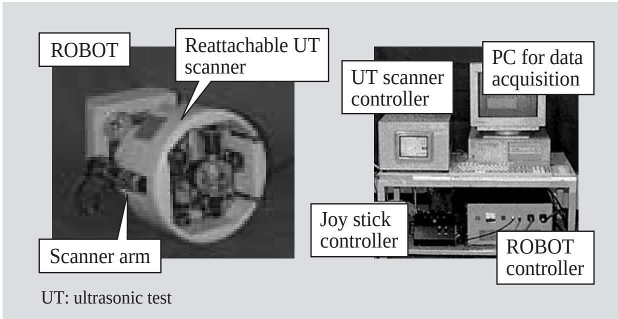


Fig. 3— Compact and Submersible ROV.
Development of this compact and submersible ROV enables visual inspections to be performed in complicated/narrow structures difficult for past inspections. The ROV mounts a reattachable UT scanner.

exposure reduction, and technologies to deal with aging in relation to preventive maintenance and inspection, repairing and replacing, etc. (Fig. 2).

DEVELOPMENT OF INSPECTION TECHNOLOGIES

Achieving 60-year operation in a nuclear power plant requires that equipment used in such long-term operation be evaluated and checked for fitness and reliable operation. In this regard, an inspection and diagnosis evaluation of an aged plant needs technologies for (1) evaluating deterioration in materials, (2) improving the reliability of inspections and diagnoses, and (3) developing remote-control equipment. In particular, inspections targeting the internals of a nuclear reactor require tele-manipulation technology for accessing complicated/narrow structures and technology for evaluating equipment fitness.

Compact and Submersible ROV

There are complicated/narrow structures within a nuclear reactor where visual inspections using a video camera or other devices are difficult to perform. Hitachi has developed a compact and submersible remotely operated vehicle (ROV) (width: 200 mm; height: 200 mm; length: 230 mm) that can perform visual

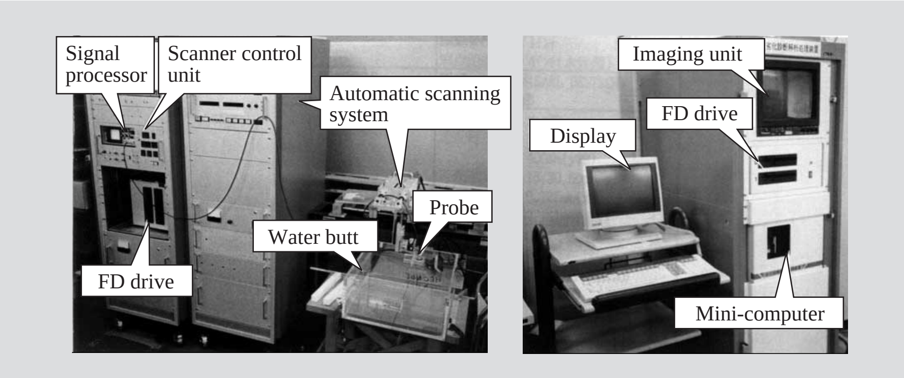


Fig. 4— Ultrasonic Holography System.
3D flaw imaging by ultrasonic holography enables non-destructive inspection of flaw size and recognition of flaw shape.

inspections even in such hard-to-get-to places. This ROV enables inspections to be performed in complicated/narrow structures that are considered difficult to access in conventional inspection work.

The configuration of this compact and submersible ROV and the layout of a test inspection of the lower section of a reactor core using the onboard camera are shown in Fig. 3.

Flaw-Evaluation Technology Using Ultrasonic Holography

To evaluate the fitness of reactor internals, the size of flaws must be measured with good accuracy. Hitachi has developed technology for displaying the size of such flaws in three dimensions using ultrasonic holography[1]. This technology enables flaws to be displayed in a solid-like manner and for inspection results to be accurately evaluated.

The configuration of this ultrasonic holography system is shown in Fig. 4.

PREVENTIVE MAINTENANCE AND REPAIR/ REPLACE TECHNOLOGIES

To maintain the reliability and cost efficiency of an operating plant, appropriate repair and replacement work must be carried out according to inspection results. We here present some examples of technical developments for repair and replacement of reactor internals.

WJP Technology

In Japan, a technology has been developed called water-jet peening (WJP) in which high-pressure water is shot at a structure to ease residual stress on the surface of a metallic material like stainless steel. This technology has been applied to reactor internals of BWR power plants.

In more detail, cavitation air bubbles are generated when shooting high-pressure water in water, and these air bubbles strike the surface of the material in question. Then, when the air bubbles collapse, an impact force of several thousand MPa is generated giving compressed residual stress to the metallic surface and preventing stress corrosion cracking from occurring (Fig. 5).

A feature of this technology is that there is no need to worry about foreign materials entering the reactor since the active fluid in this case is water, which also means that WJP can be applied to complicated/narrow structures within the reactor.

Technology for Cutting Reactor Internals

A structure inside a nuclear reactor may have to be replaced as a countermeasure to stress corrosion cracking of stainless steel. This requires technology that can cut into an activated structure inside the reactor remotely and under water. For this purpose, Hitachi has developed electric-discharged-machining (EDM)

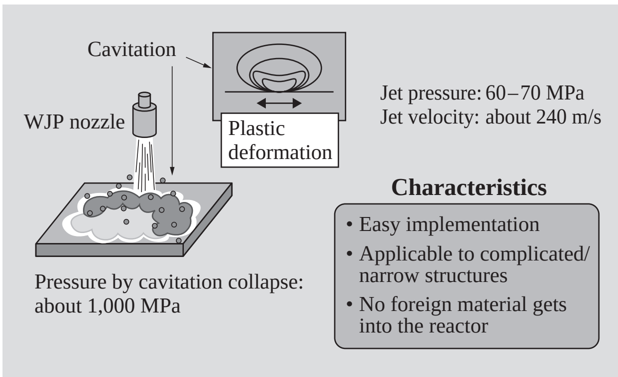


Fig. 5— Principle of WJP.
• High-pressure water shot into the water generates cavitation.
• Collapse of cavitation produces high pressure on material surface.
• Compressive stress appears on the surface because plastic deformation is elastically constrained.

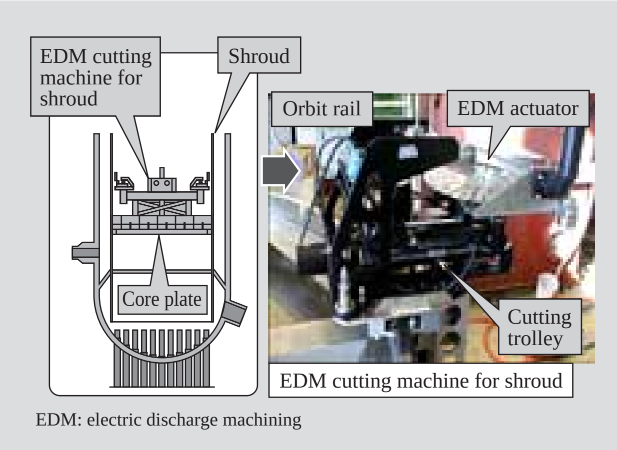


Fig. 6— Electric Discharge Machining (EDM).
EDM enables the generation of gaseous radioactive material and radioactive particle material to be greatly reduced compared to plasma cutting technology.

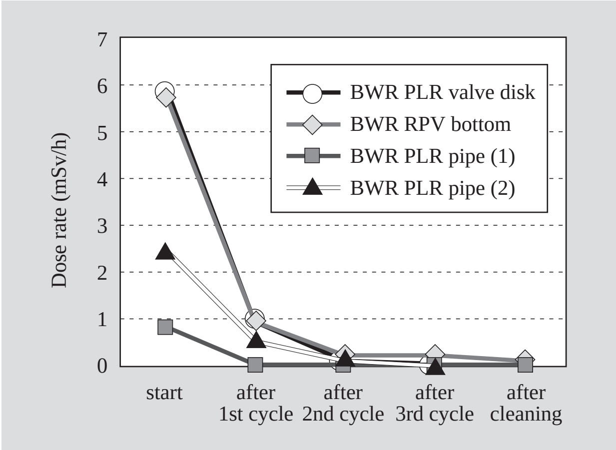


Fig. 7— Results of Applying the HOP Chemical-Decontamination Method to a BWR Nuclear Reactor.
The HOP method achieved significant reduction in occupational radiation exposure.

technology using a long-life electrode and has applied it to shroud replacement work in Japanese reactor cores.

This technology adopts in particular a long-life silver-tungsten electrode for its disk-type electrode (Fig. 6). This reduces the number of electrode replacements and minimizes the generation of secondary products like gaseous radioactive material and radioactive particle material. As a result, operators' radiation exposure can be reduced and the operating environment improved.

Chemical Decontamination Technology

Occupational radiation exposure reduction must be given consideration when inspecting, maintaining, repairing, or replacing facilities having a high dose rate such as the reactor's primary cooling system and water clean up system. Chemical decontamination is one effective means of reducing occupational radiation exposure. Hitachi has developed a chemical-decontamination method called HOP (referring to hydrazine, oxalic acid, and potassium permanganate) having both low-corrosion properties and high decontamination performance. Fig. 7 shows an example of a dose-reduction effect when applying the HOP chemical-decontamination method to the primary cooling system. Decontamination operations are performed over several days during which an extremely small amount of secondary radioactive waste under 1 m^3 will be generated. The HOP method enables a significant exposure-reduction effect to be achieved.

RVR Technology

Reactor pressure vessel replacement (RVR) technology aims to replace the reactor pressure vessel (RPV) and reactor internals simultaneously as one body. This decreases the potential of stress corrosion cracking and enables the replacement work to be completed in a short period of time. The RVR approach is receiving attention as a rationalized construction method especially appropriate for a plant life of about 60 years.

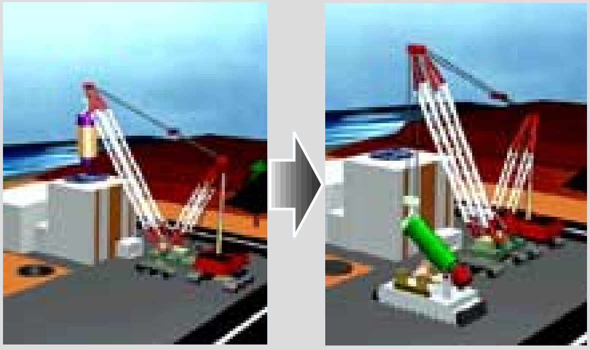
Making use of experiences gained in past construction of nuclear power plants, RVR technology will employ a large-size crawler crane to replace the RPV and reactor internals. This is expected to make construction work safer and to shorten the work period and to achieve an economically superior construction method (Fig. 8).

Research on evaluating the feasibility of RVR technology to nuclear power plants in Japan is now underway in cooperation with utility companies.

Validation of Maintenance Technologies Through Full-Scale Mock-up Tests

It is important that full-scale mock-up tests be performed as part of the development of various types of inspection and repair equipment and of construction methods needed for maintenance. The reliability of such equipment and methods must also be checked and operator training performed through tests of this kind.

To this end, the BWR Maintenance Technology Center was set up at a Hitachi site in 1994. The Center



(1) Carrying the old RPV out

The old RPV, which houses reactor internals, is carried out with a covering attached.

(2) Carrying the new RPV in

The new RPV housing reactor internals is carried in.

Fig. 8— Reactor Pressure Vessel Replacement Technology.
This technology will use a large-size crawler crane having a maximum lifting load of 1,000-1,700 t to shorten the replacement period.

Facility	Main specifications	
Test pit	Diameter 11 m × Depth 36 m	Total height 46 m
Test room	W. 20 m × L. 35 m × H. 10 m	
Lower pedestal	Diameter 6.4 m × Depth 10 m	
Water treatment	Water conductivity 2–3 S/cm (reactor water)	
	Water inventory 710 t	
Auxiliaries	Crane (2.8 t), working bridge, elevator	

Fig. 9— BWR Maintenance Technology Center.
The center is provided with full-scale facilities of a reactor pressure vessel and in-core structures, enabling the development of preventive-maintenance technology and processes for inspection and modification of major BWR equipment.

has a test pit 11 m in diameter and 36 m in depth and can simulate at full scale a reactor building from the operation floor to the lower drywell floor (Fig. 9). The center is already being used for validating technologies such as for replacing reactor internals in Japanese nuclear power plants, and is producing effective results.

CONCLUSIONS

This report has described technologies for managing aging in nuclear power plants and has discussed development trends and future directions.

Aging management for nuclear power plants has just begun. From here on, as plants continue to age, our goal is to achieve a level of plant maintenance that excels in cost efficiency while maintaining safety and reliability. To this end, Hitachi will work to develop systematic maintenance technologies and to enhance maintenance services in close collaboration with utility companies and other concerned organizations.

REFERENCES

(1) F. Takahashi et al., “Sizing and Recognition of Cracks and Porosities in Weld Metals Using Acoustical Holographic Inspection,” 1st Int. Conf. on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components, pp. 557-561 (Oct. 1998).

(2) T. Yoshimura et al., “Reduction of Residual Stress by Peening with Reflected Water Jet,” JSME Materials and Mechanics Division Meeting, pp. 469-470 (Oct. 2000).

(3) H. Takashima et al., “Chemical Decontamination Experiences on Shika Unit-1,” 10th Int. Cong. of IRPA, P-6a-300 (May 2000).

ABOUT THE AUTHORS

Tsukasa Ikegami

Joined Hitachi, Ltd. in 1974, and now works at the Preventive Maintenance Engineering Section of Nuclear Plant Service Engineering Department, Nuclear Systems Division, Power & Industrial Systems. He is currently engaged in the preventive maintenance engineering for nuclear power plants. Mr. Ikegami can be reached by e-mail at tsukasa_ikegami@pis.hitachi.co.jp.

Takao Shimura

Joined Hitachi, Ltd. in 1980, and now works at the Reactor Internal Maintenance Engineering Section of Nuclear Plant Service Engineering Department, Nuclear Systems Division, Power & Industrial Systems. He is currently engaged in the preventive maintenance engineering for nuclear power plants. Mr. Shimura can be reached by e-mail at takao_shimura@pis.hitachi.co.jp.

Masahiro Koike

Joined Hitachi, Ltd. in 1982, and now works at the Reactor Preventive Maintenance Group of Power & Industrial Systems R&D Laboratory, Power & Industrial Systems. He is currently engaged in the R&D of non-destructive inspections and diagnosis technologies. Mr. Koike can be reached by e-mail at masahiro_koike@pis.hitachi.co.jp.