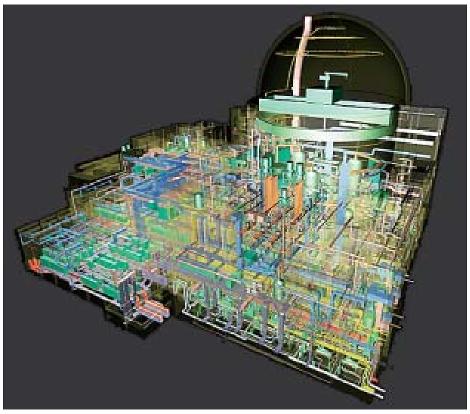


Overall Strategy for the Technology Development as the World's Leading Nuclear Company

KIYOSHI YAMAUCHI*1

KEIZO OKADA*1

Mitsubishi Heavy Industries, Ltd. (MHI) has been the sole manufacturer of pressurized water reactors (PWRs) in Japan since the commencement of commercial operations of Mihama Unit 1 of the Kansai Electric Power Company in 1970. Over these decades, MHI has endeavored to develop a broad spread of nuclear technology, from design, manufacturing, and construction to plant maintenance services. More recently, with the ever rising need for nuclear power generation around the world to prevent global warming and to cope with surging oil prices, MHI is striving to expand its nuclear power business in the world market, such as US-APWR in the U.S., as well as to develop technology for advanced reactors and nuclear fuel cycles to ensure energy security in the future. This paper introduces these approaches and clarifies the current status and future prospects of MHI as the world's leading nuclear company.

1. Introduction

MHI has constructed 23 PWR plants in Japan and through the operation and maintenance of these plants, has continued to develop and enhance the technology which meets the needs of utilities while ensuring a wide technical base as an all-round plant supplier. During this period, through the three phases of the Improvement Standardization Program for Light Water Reactors with the cooperation of the government, utilities, and suppliers, MHI has established domestic PWR technology and further enhanced plant safety, reliability, economy, operability, and maintainability and accumulated our own technology. These transitions are described from the initial plant group constructed using imported technology (nine plants in the 1970s), the next plant group constructed using MHI's own technology, designed for enhanced reliability and safety based on earlier experiences (seven plants in the 1980s), and the recent plants group based on further improvements and developments to enhance economy, operability, and maintainability (seven plants in the 1990s), see **Fig. 1**.

At present, Tomari Unit 3 (electric power: 912 MWe) of Hokkaido Electric Power Company is under construction, which has up-rated power, and enhanced operability and reliability by integrating all our brand-new technology. Tsuruga Units 3 and 4 (electric power: each 1,538 MWe) of Japan Atomic Power Company, the first units of the advanced PWR (APWR) are now being licensed. MHI is committed to the completion of these ongoing projects.

MHI has also been developing various inspection and maintenance techniques for stable operation and enhanced reliability to support utility companies, and these techniques greatly contribute to the enhancement of plant reliability through service activities.

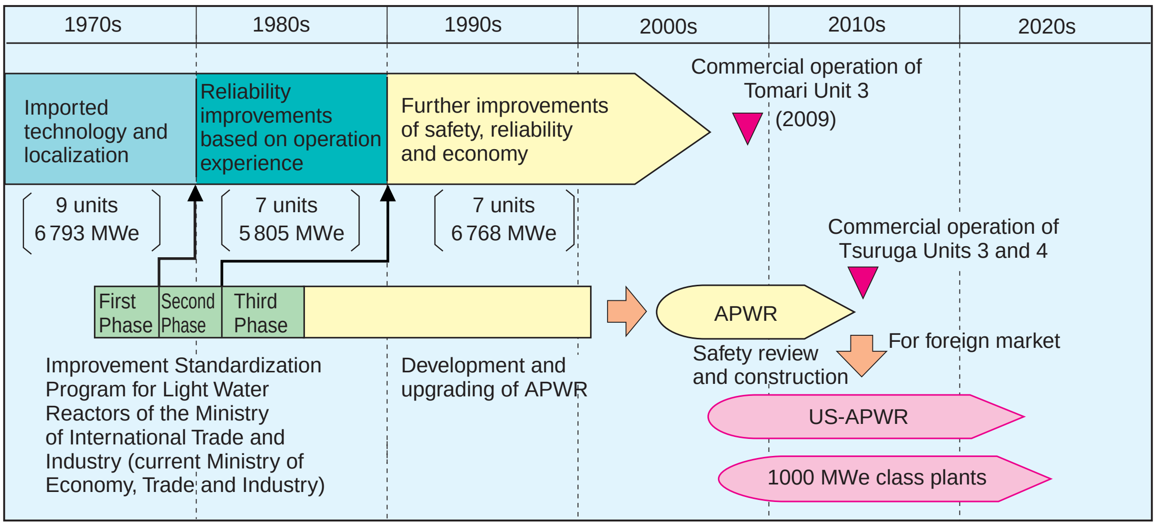
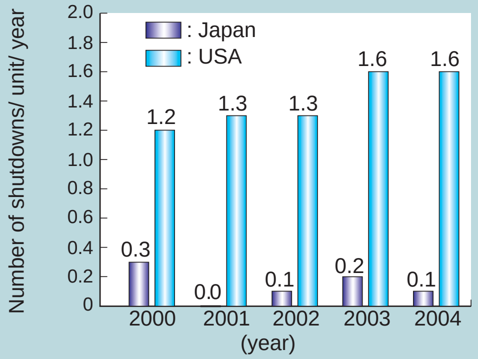


Fig. 1 Development of Mitsubishi PWR plant technology

*1 Nuclear Energy Systems Headquarters



(From) (1) Operation Status of Nuclear Facilities in Japan, Japan Nuclear Energy Safety Organization
(2) Power Reactor Status Report/ Monthly Operating Report, NRC

Fig. 2 Unscheduled shutdown rates of PWR plants

By these broad activities from design and construction to inspection and maintenance services, unscheduled shutdown rate, one of the important indicators of plant reliability, remains at 0 – 0.3 times/unit/year for the Japanese PWR plants, which indicates excellent plant performance compared with that of US plants (**Fig. 2**).

2. Technology development in light water reactor power generation plants

2.1 Trend of development of plant design

2.1.1 Approaches to new plant construction

The construction work for Tomari Unit 3 commenced in November 2003. The latest technology is applied to enhance the economy, reliability, and operability of this latest 3-loop plant. One of the main features of the plant is uprating power to 912 MWe, achieved by the combination of increased main steam pressure by raising the reactor coolant temperature and a 54-inch blade turbine system to decrease exhaust loss. Integral shroud blades are also adopted for the turbine system to enhance reliability, and its vibration characteristics, structural integrity, and performance have been sufficiently validated through full-scale rotational vibration tests and approximately 50% scale actual steam loading tests. An advanced main control board using total digital technology has been adopted to improve plant operability and economy, reducing the operator load by means of soft operation using CRTs, and reducing the cable volume through multiplex transmissions. The operability of the advanced main control board was sufficiently validated in advance using mock-up testing equipment, and the integral combined test was completed at shop by October 2006.

For other plant facilities the latest technology has been applied to enhance reliability and operability, such as iron-concentration reduction countermeasures in the main feed water (i.e. high pH operation), high-density spent fuel racks containing boron (^{10}B) effective for the maintenance of subcriticality to stretch storage capacity, and to reduce the construction period, such as large block installation of the containment vessel upper head before the onset of winter. Commercial operation of the plant is scheduled to commence in December 2009.

The first advanced PWR (APWR) applied in Tsuruga Units 3 and 4 has been developed to achieve significant improvements in economy and safety due to its large power output and innovative technology for safety systems. The development and validation was carried out mainly under the Third Phase Improvement Standardization Program for Light Water Reactors by the government, utilities, and suppliers from 1981 to 1985, and the subsequent enhancement program by the utilities and MHI, from 1986. Currently licensing is undergoing as one of the largest plants in the world, with an electric power of 1,538 MWe.

Core design has been improved to stretch the core thermal power by increasing the number of fuel assemblies from 193, for a conventional 4-loop plant, to 257, thus power is up-rated combined with the development of high-performance and large-capacity components such as steam generators, and reactor coolant pumps. A compact and high-performance steam generator adopting 3/4-inch tubes and high-performance moisture separators, and a large-capacity, high-performance reactor coolant pump have been developed for the APWR. The design of the reactor internal vessel has been improved by adopting a ring-block neutron reflector to reduce the neutron dose to the vessel to approximately one-third that of the baffle-former structure and significantly reducing the number of bolts used in the core region.

For safety design, a 4-train mechanical system configuration has been adopted to enhance the redundancy of the safety systems, and the low pressure injection system can be eliminated by the adoption of advanced accumulators with a low pressure injection function using passive technology, enabling automatic switching of the injection flow rate during accidents. The high-pressure injection system also can be simplified by adopting a direct vessel injection design to minimize the injection flow rate, which leads to the optimization of all safety systems. Further enhancement of safety can be attained by eliminating valve-switching operations during accidents through the installation of a in-containment refueling water storage pit, water source of safety components.

2.1.2 Approaches to new plant development

In the United States, the construction of new nuclear power plants waned for many years, however the U.S. market is now rising with the prospective demand for dozens of plants to be constructed up to 2030, prompted chiefly by the need to prevent global warming and cope with surging oil prices. In July 2006 MHI started the procedures to submit an application to the U.S. Nuclear Regulatory Commission (NRC) for Design Certification of the US-APWR (**Fig. 3**), a 1,700 MWe class advanced plant based on established APWR technology and modified to reflect US utility requirements by incorporating new and well-validated technology. In conjunction with that, the company has also

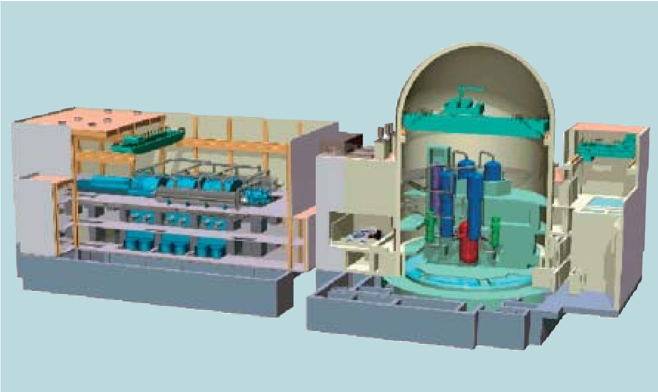


Fig. 3 US-APWR (3D-CAD model)

established MHI Nuclear Energy Systems Inc., a wholly owned subsidiary, in Washington, D.C.

The US-APWR realizes 1,700 MWe of electric power by incorporating high-performance steam generators and turbines with the same core thermal output already demonstrated by the APWR. A design with triangular-pitch tubes has been adopted for the high-performance steam generators to prevent increases in component size as much as possible while increasing the heat transfer area. The performance of the turbines is also improved by adopting new techniques such as the 70-inch class blades for low pressure turbines.

The fuel design enables economical longer cycle operation for 24 months by extending the effective fuel height from 12 ft to 14 ft and by adopting a low power density core, through the simplification of the lower reactor internals with the reactor vessel being unchanged. The in-core instrumentation is improved for top insertion, based on the requirements of US utilities, eliminating the bottom-mounted instrumentation nozzles.

The design of the emergency power supply system has been improved to four trains to realize a complete 4-train configuration of the safety systems, that enables the on-line maintenance, and gas turbine generators with simple utility equipments has been adopted for cost reduction.

The plant building design has been improved through the reduction of the volume of buildings by adopting small separate buildings allowed by lower seismic conditions in the United States.

In addition to the 1,700 MWe class US-APWR, MHI has agreed to develop a new 1,000 MWe nuclear power plant employing the latest technology in collaboration with AREVA of France, in order to cope with the demands from utilities overseas.

In Japan, meanwhile, the Framework for Nuclear Energy Policy established in 2005 enshrines the development requirements for the next generation of light water reactors to meet the demand for rebuilt plants in Japan in 2030 or later. The government is leading a plant development project in cooperation with industry and MHI is participating as the sole PWR plant supplier in Japan.

2.2 Enhancement of technology of light water reactor power generation plants

2.2.1 Core design method

To improve the core design, MHI is developing methods which enhance and maintain the prescribed design accuracy in cores loaded with high-burnup fuel. To improve the nuclear design, we have introduced a three-dimensional core calculation by enhancing and upgrading the conventional core calculation code previously used by combining the axial one-dimensional and horizontal two-dimensional codes. This core calculation code is based on the modern nodal method and can determine the core nuclear characteristics with three-dimensional calculations. With these features the code can cope with high accuracy to the advanced cores planned for the future.

An improved statistical thermal design method has been introduced to enhance the thermal hydraulic design. This will increase the flexibility of design for the selection of fuel patterns, as the thermal margin in the core is now more clearly understood. MHI has also developed ANCK, a three-dimensional core kinetic characteristics code, and MIDAC, a three-dimensional thermal hydraulic characteristics code. These codes, together with the development of the thermal hydraulic design and the application of the nuclear-thermal hydraulic coupling method to the merging of the nuclear design are now being prepared for application to actual plants. This technology, once in place, will maintain the margin of core safety at the current level and ensure the flexibility of core operation even during operation in an upgraded power state.

To provide the high accuracy necessary to cope with the complexities entailed in future work to upgrade the core, MHI is developing a three-dimensional core calculation code for the next generation of nuclear design which treats each fuel rod as a separate calculation unit. Though the method will involve immense levels of detail and require tremendous calculations, the latest acceleration calculation technology and methods such as parallel calculation, are expected to reduce the calculation time and maintain the calculation accuracy.

2.2.2 Safety design method

During the licensing of recent high-burnup fuels and MOX fuels, MHI used conservative safety analysis methods for both analysis conditions and physical models in the safety evaluations. In order to determine appropriate safety margins, MHI expects to apply new methods to further performance improvements such as up-rating power and high-burnup fuels in the future. With the recent significant progress in computer performance and numerical analysis technology, detailed modeling with simulation code becomes possible and allows the acquisition of more realistic and more accurate simulation results. MHI endeavors to develop new safety analysis methods, which can evaluate appropriate safety margins, by employing such new technology.

To improve the LOCA analysis, MHI has developed MCOBRA/TRAC, a best estimate code. This code has ability to predict the thermal-hydraulic phenomena inside the reactor vessel and the other components in the primary system of a PWR with more accuracy than the conventional deterministic evaluation method which is combined with conservative analysis conditions and physical models. At the same time, a statistical evaluation method has been developed to quantify the uncertainty of prediction. These developments have led to accurate simulations of the fuel cladding temperature and thermal-hydraulic response during LOCA, and to optimum safety margins.

To improve the non-LOCA analysis, MHI has developed the SPARKLE code. This code is a plant system transient analysis code which includes a three-dimensional core kinetics module coupled with a thermal hydraulics module. SPARKLE is distinct from the conventional evaluation method, which is done by a set of separate conservative codes, and is expected to lead to more accurate simulations of plant transients and to optimize safety margins.

MHI is preparing for examination by the regulatory agency in order to apply these new methods to the licensing analysis of power up-rating and future high-burnup fuels.

2.2.3 Plant design method

Plant design requires integration and validation activities to achieve the most effective arrangements ensuring functional requirements not only for component layouts, but also for the routes for piping, ducts and trays routings installed in buildings. Three-dimensional CAD has been fully applied to integrate and validate layouts which deal with huge amounts of data with high accuracy and effectiveness. The development and application of NUWINGS, a system for unified management of all information, from the basic design to detailed design, fabrication, and installation with the three-dimensional CAD data as its nucleus, improves the reliability and efficiency of plant design and site work.

2.2.4 Fuel design

MHI has considerable and excellent operating experience with PWR fuel since it first supplied to Mihama Unit 1 in 1970. More than 17,000 assemblies have been produced. In particular, as a result of steady root-cause analysis and countermeasures against problems (including fuel leakages), MHI has realized an excellent operating experience with no fuel leakages observed for approximately 13 years from 1991.

In the field of fuel development, MHI has reduced fuel costs by burnup extension which reduces the number of reload assemblies step by step. Recently, the utilities have applied the 55,000 MWd/t fuels licensed discharge burnup of 55,000 MWd/t in assembly average to commercial reactors. The economy and reliability of the 55,000 MWd/t fuel have been improved by a zircaloy grid for neutron economy, a corrosion resistant cladding material MDA (Mitsubishi Developed Alloy), a debris filter to increase debris trap capability, and other new technology.

To facilitate fuel development in the future, MHI is making every effort to develop advanced fuel that can realize longer cycle operation and plant uprating, as well as higher burnup fuel. To provide a further thermal margin for the uprated core, MHI has developed a new grid spacer design with high DNB performance. For higher burnup, we are developing M-MDA (modified MDA) with a corrosion resistance superior to that of the MDA currently in use. M-MDA is now under fourth cycle irradiation in a PWR plant in Spain, and its improved corrosion resistance is confirmed by third cycle irradiation. As a cladding material with more excellent corrosion resistance, the Japanese industry has developed J-Alloy^{TM}, a new material of Zr-Nb alloy. The out-pile tests are almost completed and an irradiation test commenced in a Spanish commercial PWR in April, 2006.

For the more effective use of uranium resources, domestic and foreign reprocessed uranium fuels are already being utilized in commercial reactors. Also for plutonium utilization, utilities have contracted MOX fuel fabrication in foreign countries with MHI, and MHI is preparing to fabricate MOX fuel for commercial reactors.

2.2.5 Main component design

Japanese utilities are renewing the main components of primary and secondary systems from the viewpoint of preventive maintenance, and MHI has responded to the needs of its customers for improved reliability and performance by supplying replacement components incorporating the latest technology. MHI has also received many orders for reactor vessel closure heads, steam generators, etc. from overseas mainly from Europe and the United States, since 2003, based on our experience in Japan (**Fig. 4**). The development technology for reactor vessel closure heads include the application of high nickel alloy 690 with excellent corrosion resistance for CRDM nozzle penetrations, the integrated forging of vessel head and flange, and the assembly shipping of a reactor vessel closure head with CRDMs installed for the first time in the world. Also regarding steam generators, the application of high nickel alloy, TT690, to the steam generator tubes,

Fig. 4 Transportation of reactor vessel closure head

the tube support structure at U-bend and the high performance moisture separator of MHI's own unique design improve the reliability and performance of the components.

Besides the above, MHI has completed the replacement of reactor internals in Ikata Units 1 and 2 of Shikoku Electric Power Company (**Fig. 5**) and Genkai Unit 1 of Kyushu Electric Power Company for the first time in the world and replaced the main control boards of Genkai Units 1 and 2 of Kyushu Electric Power Company. MHI also received the world's first order for a replacement pressurizer adopting high density heaters together with a reactor vessel closure head and steam generators and delivered on schedule in May 2006 to the Fort Calhoun Power Station of Omaha Public Power District. These activities are highly evaluated by customers through the strict quality control and schedule control conforming to the design and production standards both inside and outside Japan.

MHI has also improved the performance of secondary systems by replacing secondary turbines with the latest technology to domestic and overseas plants, such as replacing with longer integral shroud blades, improving drain-removal performance, and short period replacement technique of condensers tubes. MHI delivered low pressure turbines with 54-inch integral shroud blades to the KRSKO Power Station in Slovenia in April 2006 and completed the replacement work within a short period.

2.2.6 Manufacturing technologies

MHI possesses a high level of manufacturing technology for welding, machining, and assembling main components of PWR plants. In welding, MHI has developed and applied practical clad welding technology of high quality, such as electron beam welding and laser beam welding techniques to minimize the heat load for joint welding, Inconel plasma welding for steam generators, and electroslag welding for reactor vessels. The reactor vessel can be worked vertically in the same condition as when it is installed on site by the super large multi-functional NC machine Super Miller manufactured by MHI, ensuring high accuracy by excluding accumulated errors. For the manufacture of steam generators, MHI has improved the reliability of working and assembling by the exclusive use of automatic devices for insertion and expansion of the steam generator tubes. For the secondary turbines, the company possesses the integrated technology and facilities for manufacturing from the formation and working of blades, working of rotors to assembly.

With this manufacturing technology, MHI can supply high-quality components and will make continuous efforts for development and improvement.

2.2.7 Plant construction technologies

MHI has also developed various technology and techniques for plant construction work. In Tomari Unit 3, the company applied large block installation for the containment vessel upper head using a large-capacity crane (lifting capacity 1,200 t) and completed the construction work within a short period (**Fig. 6**). In Tsuruga Units 3 and 4, MHI aims at the large-scale reduction of the assembly work required inside the containment vessel by applying steel plate concrete structures to eliminate the reinforcing bars conventionally used in reinforced concrete and plans to achieve quick construction by using large-capacity cranes whenever possible for large block installation of the main steam piping room and lifting-in of heavy components, which are critical in the construction schedule.

2.2.8 Operation and maintenance technologies

After commencing the commercial operation of plants, MHI has developed and improved operation and maintenance technology in response to the needs of utilities based on its broad experience as a plant supplier.

To improve operation technology, MHI and the utilities work together on primary chemical control procedures for high-burnup fuel, optimization of the concentrations of dissolved hydrogen, suppression of scale deposition by high pH operation to prevent corrosion and degradation of secondary system components, and decontamination of steam generators.

Fig. 5 World's first replacement of reactor internals

Fig. 6 Large block installation of containment vessel upper head of Tomari Unit 3

To reduce occupational radiation exposure, MHI undertakes such measures as environmental improvement, operational improvement, and design modification. Along with its years of work for operational improvement of inspection and repair to be remote and automated in high-dose environments, MHI recently introduced zinc injection to actual plants. Zinc injection for the primary system has recently been confirmed to bring about a dose-reduction effect for environmental improvement.

A major target in maintenance technology is to simultaneously improve both the economy and reliability of maintenance work. The optimization of maintenance based on RCM (reliability centered maintenance) has attracted attention as a means of improving economy, and MHI also actively endeavors, jointly with the utilities, to optimize the frequency and content of equipment maintenance work. To improve reliability, MHI makes selective efforts to develop aging countermeasures against primary water stress corrosion cracks (PWSCC) of 600 alloy for plants with more than 30 years of operation. The developed technology includes (1) inspection techniques such as intelligent ECT (eddy current test), phased array UT (ultrasonic test) for the reactor vessel nozzle, steam generator tubes, (2) residual stress improvement techniques such as shot peening, water jet peening, and outer surface irradiated laser stress improvement process, we call L-SIP, for welds, and (3) repair techniques to improve materials by replacing 600 alloy with 690 alloy (an alloy with superior SCC resistance). MHI contributes to the stable and safe plant operation using these techniques.

3. Technology development in advanced reactor plants

3.1 Fast breeder reactor (FBR)

The FBR can breed more fuel than other reactors used to generate electricity, and the efficient utilization of uranium can be dramatically increased. These advantages have prompted research and development for the FBR as a national project. MHI has participated in the design and construction of the Experimental Fast Breeder Reactor "Joyo," and Prototype Fast Breeder Reactor "Monju," as well as the design and technology development of a demonstration reactor in collaboration with electric power companies.

Through participation in the design and construction of Joyo and Monju, MHI has acquired extensive experience in almost all stages of hardware and software development of FBR plants, including core and safety design, design and fabrication of primary components, such as reactor vessels, and steam generators. No major problems arose during construction.

From the latter half of the 1970s, MHI began design and technology development for a demonstration reactor in order to cultivate the required technological skills.

The conceptual design research of the demonstration reactor was entrusted to FBEC (FBR Engineering Co., Ltd., a jointly owned subsidiary) by Japanese power companies, and was carried out collaboratively by its four owners (MHI, Hitachi, Ltd., Toshiba Corporation, and Fuji Electric Holdings Co., Ltd.) from fiscal 1981 to 1983. Given that the design was based on Monju, the construction cost significantly exceeded that of a light water reactor at that time, which meant that construction costs had to be radically reduced. To meet that end, in 1984, MHI independently developed the "top-entry-method loop-type reactor" (**Fig. 7**), a design that significantly reduced construction costs.

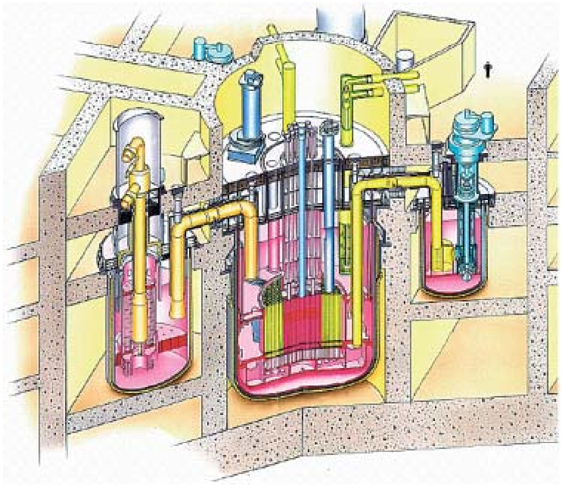


Fig. 7 Top-entry-method loop-type reactor

The design can reduce the length of the primary piping system to about half that of Monju through the installation of an intermediate heat exchanger and a primary pump into vessels, respectively, in addition to the reactor vessel; and the connection of these vessels with inverted U-shaped piping. This design configuration is made possible by the development of 316 FR steel, with better strength at high temperatures, and the upgraded assessment method in high-temperature design standards. Both technologies were the result of MHI's development efforts. Furthermore, the development of high chromium steel allows for usage of an integrated one-through type steam generator, and significantly reduces the amount of required materials. The construction cost of the reactor system, after the incorporation of other rationalization concepts, was found to be about 1.5 times more than that of a light water reactor (1,000 MWe) at that time.

After 6 years of design research on the loop-type reactor and pool-type reactor, conducted independently, but in parallel, by MHI, and Hitachi and Toshiba, the top-entry method loop-type reactor, which MHI backed, was selected by power companies in June 1990 as the design basis to be pursued thereafter. This was decided based on such results as of development experience, achievements in Japan, earthquake resistance, ease of maintenance and repairment.

It was determined that the design research, starting from 1990, should be undertaken in collaboration with all four companies. MHI has conducted extensive design research, including the engineering of the entire plant (core design, safety design, system design, layout design, etc.), as well as component and equipment design for the reactor vessels, heat exchangers, pumps, and so on. In addition, MHI has conducted extensive research and development of such areas as specific phenomena to the top-entry method loop-type reactor (such as multiple coolant level fluctuation, sloshing, gas entrainment in the coolant, etc.), study of countermeasures, upgrade of high-temperature structural design standards, development of the structural materials, development of an integrated one-through helical type SG, and so on. The collaborative design research entrusted to the four companies by the power companies ended in fiscal 1999, with a formulated plant concept. However, further cost reduction for a commercialized reactor was required.

To formulate a strategy for a low-cost and commercially viable reactor, the study "Feasibility Study on Commercialized Fast Reactor Cycle System" was initiated from fiscal 1999 chiefly under the direction of the Japan Atomic Energy Agency (JAEA). The purpose of the research was to determine the optimal technologies for the FBR cycle to flexibly respond to the various needs of society in the future through the evaluation of wide-range alternatives. Dozens of concepts in combination could be adopted for the FBR, with substantial variations in the coolants (sodium, gas, heavy metals, etc.), fuels (MOX, metals, etc.), and plant sizes. MHI has proposed seven versions of the plant concept, including large-scale and medium-scale plants, with sodium coolant (1,500 MWe and 750 MWe, respectively), a helium gas cooled plant, lead and lead-bismuth cooled plants, and small-scale plants with sodium and lead-bismuth coolant. MHI independently conducted the design research for two years during the Phase I design stage, which ended in fiscal 2000. A comparison and assessment have been carried out by JAEA and others. Among the seven concepts, six concepts, excluding the lead cooled plant concept, were selected for further investigation.

To finalize the design concept, Phase II design research was carried out for the six plant concepts until fiscal 2005. In the end, the large-scale sodium-cooled fast reactor (as shown in **Fig. 8**, 1,500 MWe, 2 loops) was selected as the primary concept. The deciding factors were high-level compliance with safety requirements (avoidance of re-criticality during core damage, etc.), cost efficiency (the construction cost in the practical application stage: 200,000 yen/kWe, etc.), low environmental burden (utilization of low decontaminated TRU fuel), etc., which are defined in "Feasibility Study on Commercialized Fast Reactor Cycle System."

The concept aims at a larger plant capacity and simultaneously adopts innovative approaches to reduce the number of loops, to employ a high chromium steel with a low thermal expansion coefficient and excellent high-temperature strength, to shorten the piping length by adopting a top flow-in/out piping system (i.e. by L-shaped pipes), to simplify the primary coolant system by employing an intermediate heat exchanger integrated with a primary pump, and so on. Those innovative approaches will cut the amount of required materials thereby reducing the cost. In addition, to present the feasibility of the concept, MHI has executed feasibility confirmation tests for the downsized reactor vessel, intermediate heat exchanger integrated with a primary pump and L-shaped piping.

There have been two reactor design selections in the past: the top-entry method loop-type reactor in 1990 by the power companies, and the large-scale sodium-cooled fast reactor in 2006 by JAEA, et al. The loop-type reactor designs developed by MHI were selected both times.

In March 2006, the Fast Reactor Cycle System was named as one of the "National Essential Technology" in the Council for Science and Technology Policy. Research and development are promoted selectively and accelerated aiming at the realization (the initiation of operation) of the FBR demonstration reactor by about 2025, and the full-scale introduction on commercial plants before 2050.

Research and development aimed at the demonstration and practical application of the FBR cycle will begin from fiscal 2007, with funds from the Ministry of Economy, Trade and Industry in addition to the Ministry of Education, Culture, Sports, Science and Technology. MHI will be in charge of the main tests on the above-mentioned innovative technologies under JAEA.

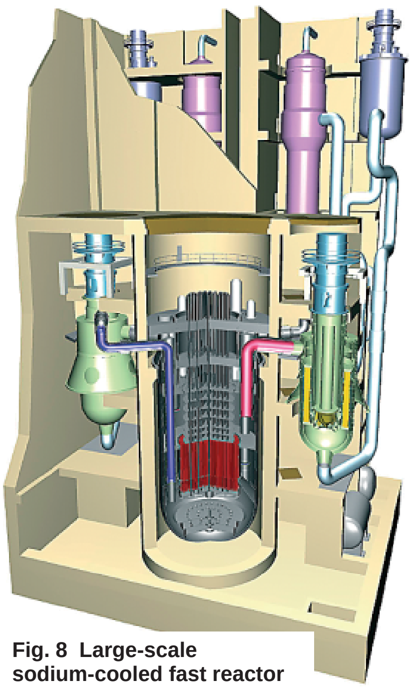


Fig. 8 Large-scale sodium-cooled fast reactor

3.2 PBMR

The PBMR (Pebble Bed Modular Reactor) is a helium gas cooled reactor that uses a type of ceramic-coated fuel particle. The reactor was developed by PBMR Ltd. capitalized by ESKOM (a state-run power company in South Africa), the South African government, etc. The output will be 400 MW of thermal power, with a reactor outlet temperature of 900°C.

MHI has been awarded the contracts for the basic design of the gas turbine as well as the basic design and material procurement of the core barrel. The fabrication and construction stages will soon follow, with the installation at site scheduled in 2009 or later.

3.3 Nuclear hydrogen production (for use in a high-temperature gas reactor)

The HTTR (High-Temperature Test Reactor) of JAEA is a coated fuel particle-graphite moderating helium gas-cooled reactor that runs at a reactor outlet temperature of 850 – 950°C. In April, 2004, it achieved the rated power of 30 MWt, with the coolant temperature of 950°C at the reactor outlet. MHI coordinates the design as an administrative company for four mechanical and electrical manufacturers, while simultaneously participating in the design and fabrication of containment vessels, high-temperature components, and so on.

For the development of hydrogen production technology by the thermo-chemical water-splitting cycle (I-S process; I: iodine and S: sulfur) utilizing high-temperature helium since fiscal 2004, MHI has fabricated a ceramics heat exchanger (SO_3 resolver) and now has a good chance of developing a component with excellent corrosion resistance at high temperature.

3.4 Nuclear fusion

In nuclear fusion, which is expected as the ultimate source of energy, MHI has actively endeavored to develop technologies and design, as well as manufacture equipment and components (mainly vacuum vessels, tritium related equipments, fuel supply and exhaust systems, etc.) for experimental fusion devices, such as the JT-60U, JFT-2M of JAEA. Such research will be utilized in the International Thermonuclear Experimental Reactor (ITER), which pursues this endeavor.

4. Technology development in the nuclear fuel cycle

4.1 Reprocessing of spent fuel

Spent fuel is considered to be a useful recyclable resource containing fissile materials such as plutonium. Japan Nuclear Fuel Limited (JNFL) has constructed a reprocessing plant applying the PUREX process (solvent extraction process) in Rokkasho-mura, Aomori Prefecture, to reprocess spent light water reactor fuel. JNFL is now in the active test stage using spent fuel with a targeted launch of operations set for fiscal 2007.

MHI supplied the key facilities in the construction of the reprocessing plant, including the facilities for acceptance, storage, chopping/shearing, dissolution, and analysis of the spent fuel. MHI has developed various techniques for the components and equipment of these facilities. MHI has also developed inspection devices for the components and piping to enhance plant operability, introduced analysis techniques for automated components to reduce exposure and labor as well as rationalized the processes to enhance economy and reduce the environmental load.

MHI contributed to the Feasibility Study on Commercialized Fast Breeder Reactor (FBR) Cycle Systems conducted as a part of the technology development program for FBR fuel reprocessing executed by JAEA and the utilities. Specifically, MHI is developing the key technological concept of the study, Advanced Aqueous Reprocessing. The company is also trying to develop a new reprocessing technology based on supercritical carbon dioxide to improve economy, as well as preprocessing processes such as disassembly of fuel assemblies, chopping/shearing, and dissolution.

4.2 Interim storage of spent fuel

The measures to increase the spent fuel to be stored until now have mainly focused on expanding the storage pool capacity. Utilities are currently proceeding with a construction plan for an interim storage facility in Mutsu City, Aomori Prefecture, which is the first off-site facility applying metal dry cask technology. The facility is expected to be in service in fiscal 2010. In Europe, especially in Germany, the interim storage using metal dry casks is advanced as a measure for increasing spent fuel.

MHI is developing the MSF series of metal dry casks with outstanding safety and economy, for interim storage. The interim storage casks must be able to efficiently store more fuel, meeting the regulations and standards for both transport and storage. MHI has endeavored to steadily develop the technology of the MSF casks as well as developing of a boron-added aluminum alloy. Demonstration tests with a full-scale model (**Fig.9**) have already been performed within the licensing procedures for MSF-57B in Germany.

Fig. 9 Mitsubishi metal dry cask (full scale model)

4.3 Treatment and disposal of radioactive waste

As treatment for low level radioactive waste generated from the operation of nuclear power plants MHI has completed various radioactive waste treatment techniques in accordance with the waste properties, including sewage treatment using activated sludge with a low amount of secondary waste generation, a micro-filtration hollow fiber treatment to enhance the backwash performance, an evaporation and concentration treatment suitable for both PWR and BWR liquid wastes, a high-pressure compacting treatment, and other methods. The adoption of these techniques has already been decided by actual nuclear power plants.

The intermediated disposal depth (50 – 100 m or deeper) for the disposal of radioactive waste with a relatively high radioactive level such as metals, concrete, etc. generated during decommissioning of power plants, etc. is planned. MHI is now involved in the basic design of this intermediate depth disposal and is establishing specifications for the waste packages to be disposed.

On the other hand, the authorities have instituted a clearance level below which waste with extremely low activity levels can be treated in the same manner as general industrial waste. Its actual implementation in nuclear facilities is expected. MHI has also developed a device capable of measuring extremely minute amounts of radiation, amounts lower than levels in the natural world, in order to effectively measure the clearance level. The first of these devices has been delivered to the Tokai Power Station of the Japan Atomic Power Company (**Fig. 10**).

Furthermore, the plan proceeds to vitrify the high level radioactive waste generated from the reprocessing facilities and to dispose of it in geological formations 300 m below ground level, or deeper. The Nuclear Waste Management Organization of Japan (NUMO) was established as the responsible organization in 2000, and an invitation for public subscription for the candidate disposal site has been issued. MHI seeks to rationalize the disposal of high-level radioactive waste by developing disposal containers (overpack), techniques for transferring waste to deep underground sites and fixing it there, and techniques for safety evaluation after final disposal.

Fig. 10 Clearance level measurement device

5. Conclusion

An overview of recent technological development activities of MHI has been presented above. Based on these technologies as a base, MHI will continue further development for the new domestic plant constructions such as Tomari Unit 3, next-generation light water reactors, and plant operating and maintenance services, with the cooperative guidance of the government and utilities. MHI will also accelerate its development of technology to further expand its business in the world market, such as the application for Design Certification of the US-APWR to the NRC, and respond to the needs of all customers as the world's leading company in nuclear power generation.

Kiyoshi Yamauchi

Keizo Okada