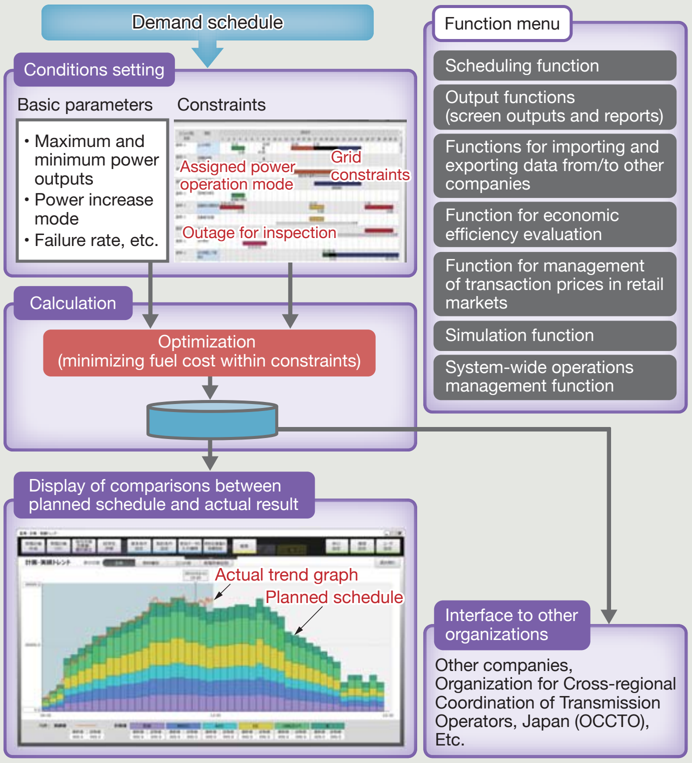
Development of Optimal and Economical Power Generation Scheduling System for TEPCO Fuel & Power, Inc.

Accompanying the deregulation of the electricity market in Japan, a new power generation scheduling system was required to systematically coordinate the operations of power plants and enable informed decisions to be made on retail electricity transactions.

Toshiba has developed an optimal and economical power generation scheduling system for TEPCO Fuel & Power, Inc. The newly developed system produces an operation schedule for each thermal power unit, including startup, shutdown, and partial load operation, so as to minimize the overall fuel cost while meeting total electricity demand. The scheduling algorithm takes various conditions into account such as the status of each generator, unscheduled outages, and atmospheric and oceanic temperatures at individual power plant sites.

Complex constraints must also be considered, including the maximum allowable rate of change in power output, upper and lower limits of fuel consumption, and restrictions caused by planned outages for inspection. The new algorithm optimizes the operation schedules for 90 thermal power units in a short amount of time.

The new scheduling system provides significant flexibility in planning power plant operations in response to their varying conditions.



Overview of optimal and economical power generation scheduling system

Shipment of Steam Turbine Rotor from Chennai Factory for Unit 2 of Kudgi Super Thermal Power Plant, India

Toshiba JSW Power Systems Pvt. Ltd. (Toshiba JSW) was founded in September 2008 with technology transfers from Toshiba. Toshiba JSW is engaged in the marketing, engineering, manufacturing, and installation of thermal power systems as well as the provision of related services.

In June 2015, the world's largest high-speed balancing machine(*) went into operation at its Chennai factory.

The steam turbine rotor for Unit 2 of the Kudgi Super Thermal Power Plant, a coal-fired supercritical generation plant operated by NTPC Limited in India, was tested on the high-speed balancing machine at the Chennai factory and shipped in August 2015.

Drawing on its leading-edge manufacturing and quality control technologies, Toshiba JSW will play the main role in expanding our business activities in India, Southeast Asia, the Middle East, and Africa, where electricity demand is expected to increase.

(*) As of June 2015 (as researched by Toshiba)

High-speed balancing test equipment and steam turbine rotor for Kudgi Super Thermal Power Plant Unit 2, India

Retrofitting of HIP Turbines at Yallourn Power Station, Australia

Toshiba completed the retrofitting of the high- and intermediate-pressure (HIP) turbines at Yallourn Power Station Units 1 and 2 of EnergyAustralia Pty Ltd in June 2014 and June 2015, respectively. The previous steam turbine generators were supplied by us and were respectively commissioned in 1974 and 1975. They were the first utility-scale steam turbine generators that we delivered to Australia.

In this retrofitting project, the new HIP turbines were supplied by Toshiba in Japan and installed by Toshiba International Corporation Pty Ltd in Australia with technical advice and assistance provided by Toshiba.

The new HIP turbines incorporate several new technologies such as the "Advanced Flow Pattern" airfoil, a sensitized packing ring, and a high-pressure (HP) stage with a larger number of stages due to optimization of the design. Furthermore, a partial inner casing was utilized in the HP section in order to reduce the total turbine weight to less than the maximum load of the overhead crane at the power station.

Through the use of these new technologies, the performance guarantee target was increased from 366 MW to 372 MW without changing the flow rate of main steam. The installation of the new turbines has been successfully completed, and both Units 1 and 2 have achieved an output of 380 MW.

HIP turbine at site of Yallourn Power Station, Australia

Migration of Control System for Thermal Power Plant Using TOSMAP-DS™/LX Controllers

The control system of Unit 2 of the Tanjung Bin Power Plant in Malaysia had been using Toshiba's previous-generation controller for more than 10 years. In order to improve its performance and maintainability, Toshiba implemented a migration(*) of the control system to the latest TOSMAP-DS™/LX controller.

Since TOSMAP-DS™/LX is compatible with the previous controller, it works well with the existing input and output equipment. In addition, the previous and new controllers can be used in the same system. We were therefore able to reuse the existing input/output modules and external instrumentation cables, making it possible to complete the migration in a short period of time.

Furthermore, the new control system allows plant operators to continue using the familiar human-machine interface (HMI) and operating procedures.

TOSMAP-DS™/LX requires no modification to other existing parts provided by third parties that are connected to it. Therefore, TOSMAP-DS™/LX provides great flexibility in migrating part of a control system according to the current plant conditions.

(*) To upgrade an existing control platform to the latest model without changing control applications

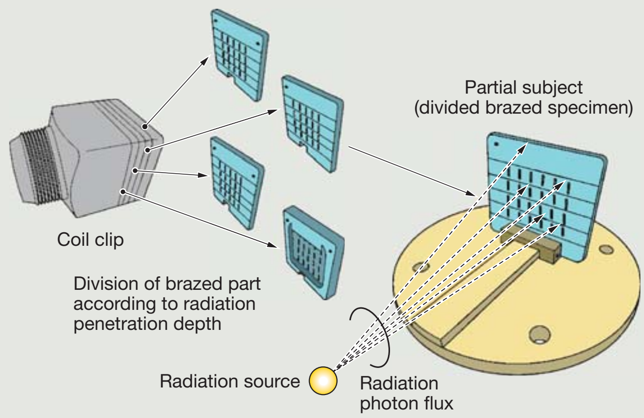
TOSMAP-DS™/LX controllers

Migration of control system for Tanjung Bin Power Plant Unit 2, Malaysia, using TOSMAP-DS™/LX controllers

New Method for Inspection of Water-Cooled Stator Bars for Turbine Generators

The brazing process is highly important in the manufacturing of water-cooled stator bars for large-capacity turbine generators because it affects the long-term reliability of the generator. Each stator bar is composed of both hollow and solid conductors and is directly cooled by passing water through the hollow conductors. The ends of a stator bar are brazed to water boxes in order to form electrical contacts and to seal the cooling water inside the water boxes. Because of the highly complicated flow path of the brazing filler material in this structure, it is difficult to evaluate the state of brazing using the conventional inspection method.

Toshiba has developed a new method for the inspection of prototype samples using X-ray apparatus to realize quantitative evaluation of the brazing quality of stator bars. Since the conventional inspection method relies on visual inspection of the cut cross-section of a water box, the inspection of prototype samples has been restricted. In contrast, the new method can quantitatively evaluate the entire brazed portion of a water box.



Technology for quantitative evaluation of stator bar brazing quality

The main features of the new inspection method are as follows:

- High resolution is achieved by the use of high-precision X-ray examination apparatus.
- Quantification is performed by comparing the brazing state with a calibration piece. The measured values obtained at multiple points of a water box are aggregated to evaluate the overall brazing quality. Moreover, the system incorporates newly developed software that significantly reduces the time required to evaluate large volumes of measurement data.

D4 Series Generator and Transformer Protection Relay

Chubu Electric Power Co., Inc. has decided to utilize the D4 series generator and transformer protection relay at its Nishi-Nagoya Thermal Power Station Unit 7, marking the first deployment of the D4 series in Japan.

Toshiba has developed the D4 relay as a successor to the D3 relay in order to meet the requests of protection relay users for improved reliability, long-term supply capability, and maintainability. The D4 relay delivers a three- to fivefold improvement in computing performance(*), more versatile functions, an approximately 50% reduction in parts count(*), and a decrease in the amount of heat generated. These improvements have been realized through the use of the latest hardware devices such as a high-speed, low-power-consumption processor and a high-speed memory.

As a result, the D4 relay has a mean time between failure (MTBF) exceeding 150 years, an approximately threefold improvement(*).

The D4 relay is expected to be installed in power stations both in Japan and overseas in the future.

(*) In comparison with the D3 relay

*Artist's impression

D4 series generator and transformer protection relay

Application of Carbon Capture Technology to Steel Plant

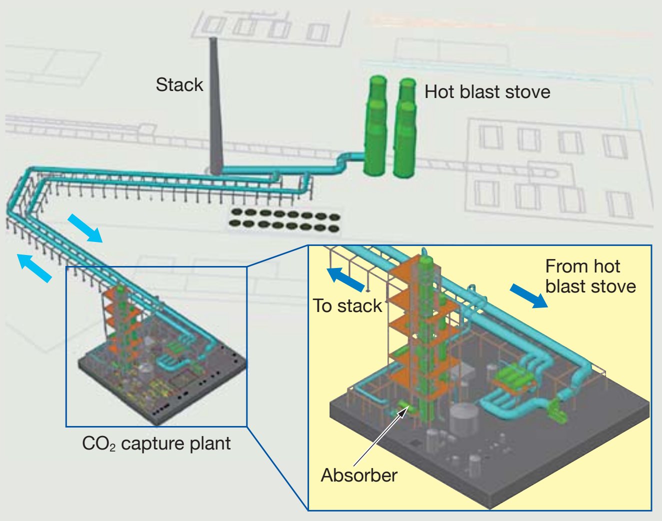
Toshiba has performed a feasibility study of its carbon capture technology at a steel plant in order to evaluate and prove its applicability to general industry.

In China, where environmental concerns are acute, reducing the carbon dioxide (CO_2) emissions of the steel industry is an urgent issue. Recognizing that the Chinese steel industry may be a potential area of application of our carbon capture technology, we selected a steel plant in China as the site of this feasibility study.

Since a steel plant emits various types of exhaust gases and has a variety of heat sources on its premises, we first identified an appropriate combination of an exhaust gas and a heat source for CO_2 capture. We used our CO_2 capture pilot plant to measure its performance for the selected exhaust gas at the simulated CO_2 concentration and then evaluated the design and economy of our capture plant.

We will continue to investigate other areas for the application of this technology in general industry.

This study was partly funded by the Global Carbon Capture and Storage Institute.



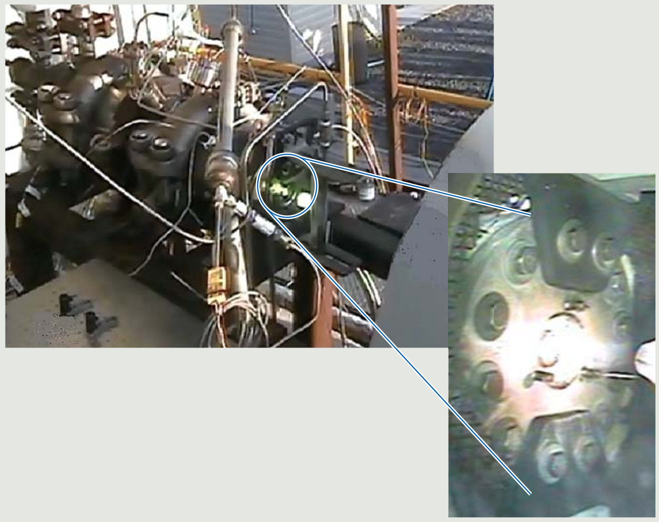
Example of CO_2 capture plant layout

Completion of Combustion Test of Supercritical CO_2 Combustor

A project for the development of an innovative supercritical CO_2 power generation system capable of capturing and reusing waste CO_2 in the power generation cycle has been progressing, led mainly by four U.S. companies: 8 Rivers Capital; NET Power, LLC; Chicago Bridge & Iron Company (CB&I); and Exelon Corporation. The new technology offers higher energy efficiency.

In this project, Toshiba is responsible for the development of a high-temperature and high-pressure turbine and combustor as key components of the system. In January 2013, we started a series of combustion tests at a combustor test facility in the U.S.A., which were successfully completed in November 2015. Tests were conducted using the actual CO_2 turbine cycle at pressures as high as 30 MPa and a combustor exit temperature of 1150°C, as well as under baseload conditions. Furthermore, tests were also conducted under off-design operating conditions. Through these tests, data on exhaust gas were acquired to evaluate its concentration levels. In addition, the lean flame blow-out limit of the fuel and the stable operating region of the combustor were tested. These tests provided valuable data for the development of a supercritical CO_2 power generation system.

A pilot supercritical CO_2 power plant is now under construction, with a demonstration test scheduled to begin in March 2017.



Combustion test of supercritical CO_2 turbine at pressure of 30 MPa

Commencement of Commercial Operation of First Pumped Storage Units Supplied by THPC at Qingyuan Pumped Storage Power Station, China

The Qingyuan Pumped Storage Power Station of China Southern Power Grid Co., Ltd. has four pumped storage units with a pumping head of more than 500 m and a capacity of 320 MW. The contract for this power station was the first pumped storage project for Toshiba Hydro Power (Hangzhou) Co., Ltd. (THPC), a subsidiary of Toshiba in China.

Unit 1 started commercial operation in November 2015, followed by Unit 2 in March 2016 and Unit 3 in June 2016. Unit 4 is scheduled to begin commercial operation in August 2016.

The pump-turbines and generator-motors were designed by Toshiba, and most of their components were manufactured by THPC. The electromechanical balance-of-plant (BOP) systems, including a supervisory control system, protection relays, main circuit facilities, and piping systems, were purchased and supplied by THPC. The commissioning tests of the entire power station were jointly conducted by Toshiba and THPC.

A splitter runner consisting of long and short blades was employed to reduce pressure fluctuations and vibration, even during partial-load operation.

The ratings of the pump-turbines and generator-motors are as follows:

- Pump-turbines: 326.5 MW-470 m/509.08 m-428.6 min^{-1}, 4 units
- Generator-motors: 356 MVA-15.75 kV-428.6 min^{-1}, 4 units.

Qingyuan Pumped Storage Power Station, China

Splitter runner

Commencement of Commercial Operation of Two Adjustable-Speed Pumped Storage Systems at Kyogoku Hydroelectric Power Station

Unit 2 of the Kyogoku Hydroelectric Power Station of Hokkaido Electric Power Co., Inc. entered commercial operation on November 1, 2015, following the commencement of commercial operation of Unit 1 in October 2014. The Kyogoku Hydroelectric Power Station is the first power station to which Toshiba has delivered adjustable-speed pumped storage systems for two units at the same power plant.

The two units can start pumping back to back, with either one of them acting as a driving generator. The advantages of an adjustable-speed pumped storage system include a wide turbine output range and adjustable pump input. In total, the two units of the Kyogoku Hydroelectric Power Station have a turbine output range adjustable from 0 to 400 MW and a pump input range adjustable from 314 to 470 MW. These adjustable-speed pumped storage systems are expected to reduce grid frequency fluctuations caused by fluctuations in wind, photovoltaic, and other renewable power generation systems, thus helping to maintain the stability of the electric power grid.

The ratings of the pump-turbines and generator-motors are as follows:

- Pump-turbines: 208/230 MW-414.2 m-500 $\text{min}^{-1}\pm5\%$, 2 units
- Generator-motors: 230 MVA/230 MW-16.5 kV-50 Hz-500 $\text{min}^{-1}\pm5\%$, 2 units.

Kyogoku Hydroelectric Power Station of Hokkaido Electric Power Co., Inc.

Start of Commercial Operation of Large-Capacity Kaplan Turbines at Kaleta Hydropower Station, Guinea

All three hydro generator units at the Kaleta Hydropower Station in Guinea started commercial operation in August 2015.

THPC was awarded a contract for this project. Toshiba took charge of the development process for fulfillment of the turbine performance requirements, and THPC undertook all of the design and manufacturing functions for the turbines and generators.

The maximum head of the turbines is 50.3 m, which is relatively high for Kaplan turbines. The turbine runners have six blades, and a double-link structure is employed for the blade operating mechanism.

The Kaleta Hydropower Station is the largest hydroelectric power plant in Guinea. This project has been a focus of attention in the country, as reflected by the image of the power station that appears on a new 20 000-franc Guinean banknote.

- Turbines: 80.17 MW-4.85 m-166.67 min^{-1}, 3 units
- Generators: 92 MVA-10.5 kV-166.67 min^{-1}-50 Hz, 3 units.

Kaleta Hydropower Station, Guinea

Commencement of Commercial Operation of 666.67 MVA Generator at Guanyinyan Hydropower Station, China

THPC has designed and manufactured two generators for the Guanyinyan Hydropower Station in Sichuan, China. The first unit began commercial operation in December 2015, and the second unit is scheduled for commissioning in 2016.

With a capacity of 666.67 MVA and a rotor diameter of 16.1 m, these generators are the largest manufactured so far by THPC. Because of their size, shrink-fitting of the rotor rim assembly was requested. In addition, to reduce the high level of stress that the rotor spokes of such large-diameter machines are subjected to, we adopted an oblique rib structure in which the ribs of the rotor spokes are inclined in the circumferential direction of the central body.

Since THPC had no experience with either 600 MVA-class generators or 20 kV stator coils, the stator was jointly developed with Toshiba, which provided technical support. To increase the buckling strength of the stator core, a core through-bolt structure was utilized as in previous generators manufactured by THPC.

- Generator ratings: 666.67 MVA-20 kV-90.9 min^{-1}-50 Hz.

Generator rotor for Guanyinyan Hydropower Station, China

Generator stator for Guanyinyan Hydropower Station, China

Commercial Operation of Alasehir Geothermal Power Plant in Turkey

Toshiba supplied a 29.59 MW steam turbine, a generator, and a condenser to the Alasehir Geothermal Power Plant in western Turkey and provided a technical advisory service for its erection and commissioning. The Alasehir Geothermal Power Plant started commercial operation in 2015.

This project marked the first time for Toshiba to supply a steam turbine generator system in Turkey and also the first case of joint operation of our steam turbine generator together with a binary power plant system.

The configuration of this unit is unique in that HP and low-pressure (LP) turbines are housed in one casing. The first flash steam with a high content of non-condensable gas flows into the HP back-pressure steam turbine, and its exhaust gas is reused in the binary system. The second flash steam with a relatively small content of non-condensable gas flows into the LP condensing steam turbine, and the exhaust steam from it is discharged to the condenser.

This configuration helps to improve the efficiency of geothermal resource utilization. Our highly reliable state-of-the-art technology is expected to open up new opportunities to further contribute to geothermal power generation.

Alasehir Geothermal Power Plant, Turkey

Turbine generator for Alasehir Geothermal Power Plant, Turkey

Start of Commercial Operation of Toshiba's First Skid-Mounted Wellhead Geothermal Power Generation System in Japan

Toshiba's first skid-mounted wellhead geothermal power generation system in Japan, delivered to the Waita Geothermal Power Plant of Chuo Electric Power FURUSATO Geothermal and New Energy Co., Ltd., commenced commercial operation in June 2015. We have been entrusted with the task of power production by Waita-Kai Company, a limited liability company.

This geothermal plant is located in the town of Oguni in Aso-gun, Kumamoto Prefecture. The steam turbine generator for this plant has a standardized design featuring compact dimensions, a short installation lead-time, an output of 1 000 to 2 000 kW, and high-temperature flash steam.

Waita Geothermal Power Plant equipped with skid-mounted wellhead generator

Social Infrastructure ▶ Power Systems

Acceptance Review of Specialized Seismic Option Report for AP1000™ Plant Completed by U.S. NRC

The AP1000™ plant was developed by Westinghouse Electric Company LLC, a member of the Toshiba Group. The AP1000™ plant is a state-of-the-art Generation III+ pressurized water reactor (PWR), characterized by passive safety systems. The AP1000™ plant design was certified by the U.S. Nuclear Regulatory Commission (NRC) in 2011. There are eight AP1000™ plants under construction: four in China and four in the United States.

The seismic design of the AP1000™ plant covers conditions in many areas in the world. In order to extend the range of applicability of the AP1000™ plant, Westinghouse and Toshiba prepared a Specialized Seismic Option Report for this plant. The report was submitted to the NRC by Westinghouse in September 2015. The NRC completed its acceptance review of the report in December 2015, and approval is expected in 2017.

The Specialized Seismic Option will be utilized for global market expansion to select locations with higher seismic levels, levels similar to those typical of certain portions of the western United States, and certain other global markets.

The analysis for the Option Report confirmed that a limited number of customized materials and/or reinforcements will provide the same advanced safety features, modular design, and simplified systems as the standard NRC-certified AP1000™ plant technology.

Specialized Seismic Option Report for AP1000™ plant

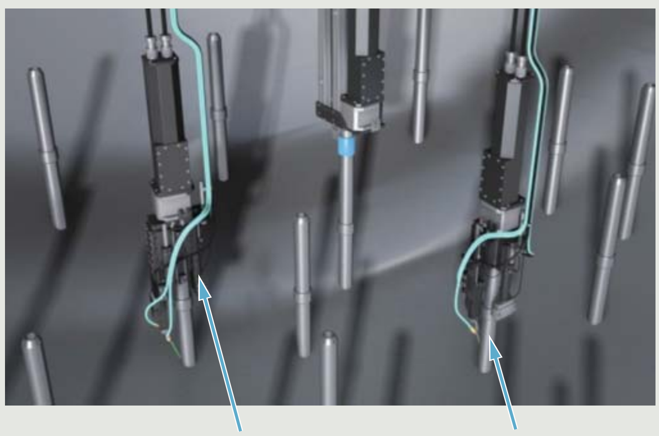
Laser Peening of Reactor Internals in U.S.A.

Stress corrosion cracking (SCC) at the weld joints of the nozzles of aged PWRs is a major concern.

Toshiba provides a laser peening solution for SCC to reduce residual stress on metal surfaces. We have applied laser peening to a number of PWRs and boiling water reactors (BWRs) in Japan. The Electric Power Research Institute (EPRI), a U.S. organization, has also highly evaluated our laser peening technology.

Conventionally, laser peening technology has been utilized underwater. We have developed a laser peening technology that utilizes a water shower in the air to achieve an effect equivalent to that of underwater laser peening, so that laser peening can also be applied to reactor vessel closure heads (RVCHs) of PWRs that are located on the refueling floor during outage.

In recognition of this technology's benefits, Toshiba and Westinghouse have been awarded contracts by the U.S. nuclear industry for bottom-mounted instrumentation (BMI) nozzles and RVCH nozzles at two PWR plants in the United States.



Laser peening of reactor BMI nozzles

Drop-in Solution for Rod Control System Logic Cabinets

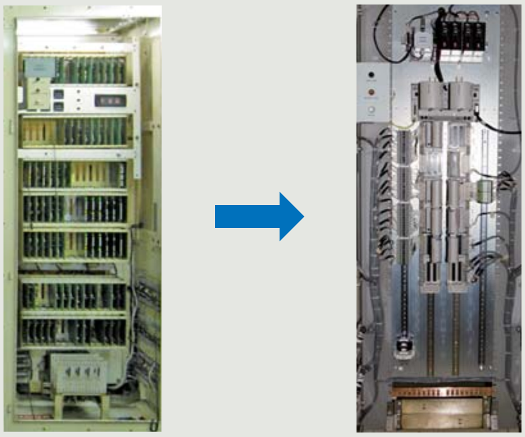
Westinghouse has developed a drop-in solution for rod control system logic cabinets based on the Ovation(†) digital information and control (I&C) platform for all configurations of Westinghouse's PWR operating plants. The standardized design of the unit is modular, allowing it to be adapted to the interface requirements of each rod control system, and it mounts into the existing logic cabinet enclosure.

This drop-in solution reduces the probability of a dropped control rod or rod motion error. By transferring the functionality of 70 analog logic cards of 25 different types and various numbers of switches and relays into software on a highly reliable, redundant system, many potential points of failure have been eliminated. HMI displays are incorporated into the design to provide redundant control and indication of the main control board (MCB) hardware.

The drop-in solution benefits the utility in terms of installation, reliability, maintenance, troubleshooting, and reduced inventory. Each benefit factors into the elimination or reduction of critical path activities that could extend outages or delay plant startup following an outage.

The drop-in solution is scheduled for its first installation at Exelon Corporation's Braidwood Generating Station Units 1 and 2 in the autumn of 2016 and spring of 2017. The drop-in solution can be applied to more than 70 operating plants worldwide.

Ovation is a trademark or registered trademark of Emerson Process Management Company.



Original rod control cabinet

Drop-in solution for rod control system logic cabinet

Drop-in solution for rod control system logic cabinet in existing Westinghouse PWRs

Westinghouse Annular Thermal Crud Hydraulics (WATCH) Loop

A new test loop, named the Westinghouse Annular Thermal Crud Hydraulics (WATCH) Loop, is a single-rod BWR simulation loop that was recently constructed at the Westinghouse Churchill site near Pittsburgh, Pennsylvania, U.S.A. The loop was designed to grow simulated BWR crud under normal BWR operating conditions, having typical fluid velocities, temperatures, pressures, and heat transfer rates.

This new loop can be utilized to (1) benchmark computer codes for BWR crud prediction; (2) validate current friction correlations and pressure drops at crudded fuel rod surfaces; (3) better understand and predict crud behavior under BWR operating conditions; and (4) make other measurements, such as fuel rod heat transfer enhancement with three-dimensional (3D) surface roughness.

The loop has also been used to study BWR fuel assembly orifice flow blockage. The flow blockage testing allowed a plant with a potential foreign material intrusion to safely return to full power without shutting down.

WATCH Loop

Delivery of Spent Fuel Pool Water Level and Temperature Instrumentation Systems to Laguna Verde Nuclear Power Plant in Mexico

Toshiba has developed and supplied spent fuel pool water level and temperature instrumentation systems (SFPIS) to Laguna Verde Nuclear Power Plant Units 1 and 2 operated by Comisión Federal de Electricidad (CFE), Mexico.

A float-level switch has conventionally been utilized in spent fuel pools to measure the normal water level. However, in the wake of the accident at the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (TEPCO Holdings), the U.S. NRC has mandated the measurement of the water level from the normal water level to the top of the active fuel (TAF) in the event of a severe accident.

Our SFPIS, equipped with heaters and thermocouples, measures the water level based on the difference in heat transfer between water and air. It has the following features: (1) The sensors are fabricated with inorganic materials that are resistant to degradation even under severe accident conditions (high temperature and radiation). (2) The SFPIS is designed to meet the seismic requirements at the Laguna Verde site. (3) The SFPIS has been verified through environmental, seismic, and electromagnetic compatibility tests as equivalent to Class 1E as per the relevant U.S. standards.

We completed the installation and on-site acceptance test of the SFPIS for Laguna Verde Unit 1 in January 2016 and delivered the SFPIS for Unit 2 in March 2016.

Heat-thermo type spent fuel pool water level and temperature measurement sensor

Method for Evaluation of Seismic Isolation Systems for Nuclear Power Facilities

Toshiba has established a method for the evaluation of seismic isolation systems to improve the safety of seismic isolation buildings in nuclear power facilities. The major achievements of this project are as follows:

- verification of the breaking characteristics of a seismic isolator using a full-scale seismic isolator break test machine
- verification of the seismic response and failure behavior of crossover piping using a shaking table
- establishment of a seismic probabilistic risk assessment (PRA) method for seismic isolation buildings in nuclear facilities.

Joint research and development was carried out as a national project from 2008 until March 2016 in cooperation with electric power utilities operating BWRs and PWRs, The Institute of Applied Energy, Mitsubishi Heavy Industries, Ltd., and Hitachi-GE Nuclear Energy, Ltd.

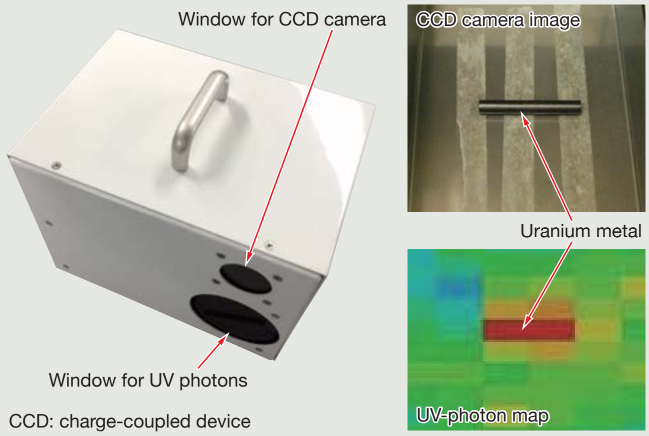
Full-scale seismic isolator break test machine

Novel Alpha-Ray Measurement Method

It is mandatory to measure the alpha radiation levels of working areas and all items used in uranium-related facilities. Conventional alpha radiation detectors must be placed close to the area or item to be measured because alpha particles have a short range in air. The members of the on-site crew performing such measurements are therefore exposed to high doses of radiation.

To address this issue, Toshiba has developed a portable alpha-ray camera that detects the ultraviolet (UV) light emitted by nitrogen when irradiated by alpha particles. This camera can remotely detect radioactive contamination by superimposing a UV light distribution image on a background image. The prototype of the alpha-ray camera measures 138 × 202 × 155 mm. The right-hand part of the figure shows images of a uranium metal sample taken by this alpha-ray camera.

The alpha-ray camera makes it possible to shorten measurement time and reduce the exposure dose of the on-site crew. We are planning to utilize it for radioactive contamination inspection work, such as during the decommissioning of the Fukushima Daiichi Nuclear Power Station of TEPCO Holdings.



CCD: charge-coupled device

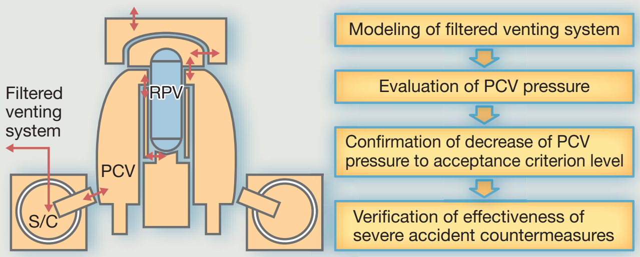
Prototype alpha-ray camera and output images

Evaluation of Effectiveness of Severe Accident Countermeasures Using MAAP Code

Countermeasures against severe accidents and accident management procedures are currently under development at nuclear power plants in Japan to enhance their safety and meet the new regulatory requirements for restarting their operations. To confirm the effectiveness of these countermeasures and procedures for the mitigation and termination of severe accidents, Toshiba has been conducting safety analyses using a severe accident analysis tool called the Modular Accident Analysis Program (MAAP), while also contributing to its development and improvement.

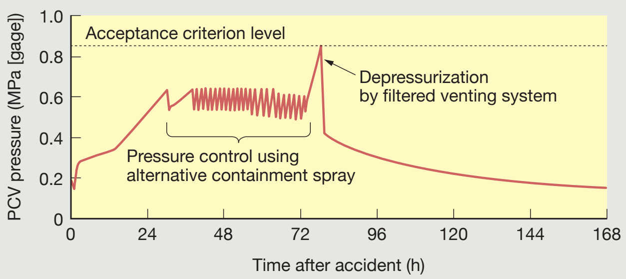
The MAAP code simulates various physical and chemical phenomena that might occur during a severe accident, including the complex thermal-hydraulic behavior of phenomena inside the reactor. It also calculates the release and transportation of fission products inside the reactor pressure vessel (RPV), primary containment vessel (PCV), and reactor building. MAAP is used internationally by electric power utilities and plant manufacturers to conduct various safety analyses.

The results obtained with the MAAP analyses indicate that the severe accident countermeasures and procedures are effective in mitigating severe accidents and satisfy the new regulatory requirements. These results are currently under examination and review by the Nuclear Regulation Authority (NRA) of Japan.



S/C: suppression chamber

MAAP PCV model



Example of result of MAAP analysis of PCV pressure during accident

Completion of Treatment of Highly Contaminated Water at Fukushima Daiichi Nuclear Power Station

Immediately after the severe accident at the Fukushima Daiichi Nuclear Power Station, Toshiba established a large water treatment loop, including a cesium (Cs) removal system named SARRY™ (Simplified Active Water Retrieval and Recovery System) that reuses the reactors' cooling water. In addition, we installed a series of systems called MRRS™ (Multi-radionuclide Removal System) capable of removing almost all of the radionuclides from highly radioactive reverse-osmosis (RO)-concentrated water.

Subsequently, MRRS™ was urgently improved based on the initial operation experience in order to maintain its availability. In addition, we quickly delivered mobile strontium (Sr) removal systems and added a Sr removal function to SARRY™.

These efforts have greatly contributed to the accelerated treatment of contaminated water. As a result, Tokyo Electric Power Company(*) declared in May 2015 that it had completed the treatment of approximately 620 000 tons of RO-concentrated water. The total throughput of the Toshiba-delivered facilities reached approximately 450 000 tons, almost three-quarters of the total volume treated.

We will continue to make our best efforts to achieve the final completion of contaminated water treatment at the Fukushima Daiichi Nuclear Power Station.

(*) Currently TEPCO Holdings

MRRS™ system at Fukushima Daiichi Nuclear Power Station

Remote-Controlled Robot for Internal PCV Investigation

Toshiba has developed a remote-controlled robot to investigate the melted fuel debris inside the PCV of the Fukushima Daiichi Nuclear Power Station Unit 2 of TEPCO Holdings.

Although it was difficult to find access routes to the inside of the PCV because of the high-level radiation environment around the PCV, a part with an inside diameter of approximately 10 cm could be drilled a hole was selected as the point from which the robot would be guided into the PCV.

The robot has a camera and lights on its rear section. The rear section is deployed backward in line with the body when the robot passes through the hole. Once the robot reaches the PCV, the rear section is raised like the tail of a scorpion. The rear section can be swiveled to capture a wider area of the PCV than is possible in the backward-deployed position. This mechanism also works like an arm, making the robot self-righting in the event of a rollover.

Using the robot, we are planning to investigate the fuel debris in the PCV for the first time since the accident.

The development of this robot was subsidized as part of the project for restoration from the nuclear reactor accident led by the Agency for Natural Resources and Energy.

Remote-controlled robot for internal PCV investigation

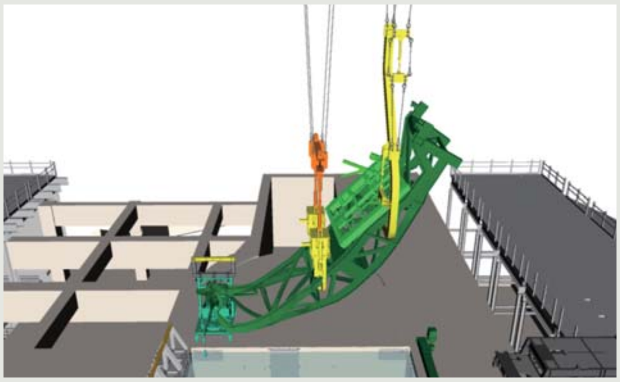
Completion of Removal of Large Debris from Spent Fuel Pool of Fukushima Daiichi Nuclear Power Station Unit 3

Due to the Great East Japan Earthquake, the spent fuel pool (SFP) at Fukushima Daiichi Nuclear Power Station Unit 3 of TEPCO Holdings was littered with large pieces of debris such as steel frames of the reactor building and the fuel handling machine, which had to be removed.

However, the atmosphere around the SFP was so high in radiation that Toshiba had to carefully plan a remote-controlled procedure for removing this debris without causing any damage to the fuel.

For this purpose, we studied where to cut the debris to prevent interference, where to securely grasp it to maintain its balance, and how to monitor debris removal operations by simulating the whole procedure using 3D computer-aided design (CAD) models of the debris created from photographs.

As a result, we successfully completed the removal of all the large debris from the SFP, including the deformed 20-ton fuel handling machine, as scheduled.



Simulation of fuel handling machine removal

Fuel handling machine removal operation at site

Manufacturing and Installation of Contaminated Water Storage Tanks for Fukushima Daiichi Nuclear Power Station

Toshiba has designed, manufactured, and installed tanks for storing contaminated water at the Fukushima Daiichi Nuclear Power Station of TEPCO Holdings.

Due to a shortage of storage capacity for contaminated water, it was a matter of urgency to produce a large number of storage tanks in a short period of time in order to comply with the water treatment plan.

To shorten the production lead-time, we established a dedicated production line, dispatched inspectors to the production site to ensure timely inspections throughout the production period, continually improved welding procedures based on the lessons learned at the initial stage, and simulated assembly procedures using 3D CAD.

Installation of on-site-assembled tanks

As a result, we achieved a monthly production of 11 factory-assembled tanks (1 235 m^3/unit) and a monthly installation of seven on-site-assembled tanks (2 900 m^3/unit), which exceeded our initial expectations. In December 2015, we completed the installation of 97 tanks with a total capacity of around 170 000 m^3 as scheduled. These tanks have significantly contributed to the stable storage of contaminated water, accounting for roughly 20% of the total storage capacity at the Fukushima Daiichi Nuclear Power Station.

Development of Nuclear Fuel Cycle Technologies to Eliminate Nuclear Waste

Toshiba has been developing nuclear fuel cycle technologies to reduce the radiotoxicity of nuclear waste from the spent fuel of light water reactors (LWRs) to the level of natural uranium in several hundred years instead of tens of thousands of years.

Using core physics analysis, we have confirmed a feasibility of a technology for metallic-fuel fast reactors that can efficiently consume long-lived transuranic elements in LWR spent fuel. This uranium-free project is being sponsored by the Nuclear System Research and Development Program of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.

Furthermore, we have been participating in the ImPACT (Impulsing Paradigm Change through Disruptive Technologies) Program sponsored by the Cabinet Office of the Government of Japan, the objective of which is the reduction and effective utilization of long-lived nuclear waste through nuclear transmutation. In this program, we have demonstrated the possibility of retrieving long-lived fission products from vitrified nuclear waste using a molten salt.

We will continue to develop various technologies to reduce the amount of nuclear waste and the size of final waste repositories.

Molten salt electrorefining test equipment to recover long-lived radionuclides

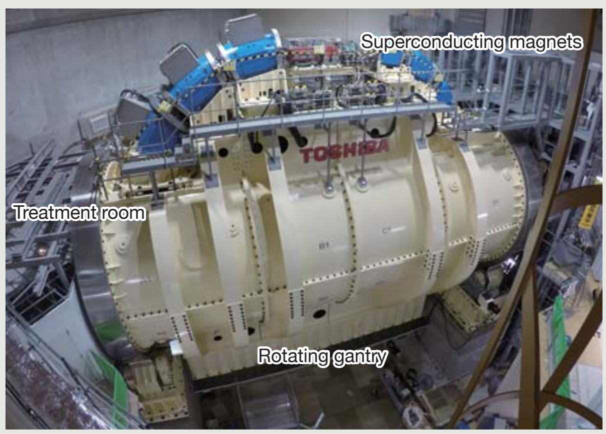
Completion of Installation of Superconducting Rotating Gantry at NIRS

In October 2015, Toshiba completed the manufacture and installation of a rotating gantry for heavy-ion radiotherapy, the first in the world to use superconducting magnets on the beam transfer line(*), at the National Institute of Radiological Sciences (NIRS) of Japan. The gantry can irradiate tumor tissues from all directions without the need to change the position of the patient. One of the benefits of a rotating gantry is the reduction of the accumulated dose to the surrounding normal tissues. In addition, it helps to reduce both patient stress and treatment time.

Due to the use of superconducting magnets on the beam transfer line, the rotating gantry achieves reductions of approximately 50% in total length and weight compared with a conventional gantry using normal conducting magnets. The rotating gantry measures approximately 5.5 m in radius and 14 m in length, and weighs approximately 300 tons.

NIRS is now performing commissioning tests and will begin clinical treatment within fiscal year 2016.

(*) As of January 2016 (as researched by Toshiba)



Superconducting rotating gantry for heavy-ion radiotherapy

Manufacturing of TF Coils and Blanket Remote Handling System for ITER

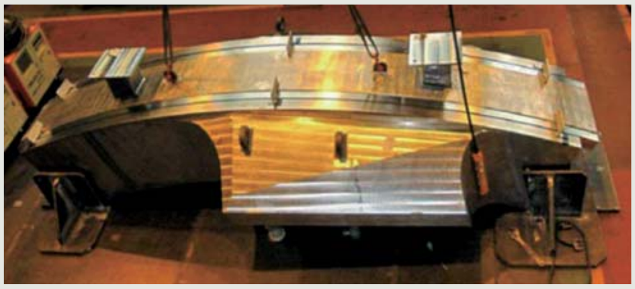
ITER is an international project to establish the feasibility of fusion energy. The project is run by seven member entities: Japan, the European Union (EU), the U.S.A., Russia, South Korea, China, and India. Site preparation began in Cadarache, France, in 2005.

Toshiba has been participating in the ITER project since the conceptual design phase and supplying major equipment for it.

Since 2013, we have been awarded contracts for the manufacturing of toroidal field (TF) coils for ITER. The TF coils are superconducting coils housed in a structure made of special stainless steel. One TF coil measures 10 m in width and 16.5 m in height, and weighs 300 tons. We will manufacture four complete TF coils as well as six structures in which the TF coils being manufactured by the EU will be housed.

Full-scale mock-ups of the TF coil and its housing structure are now being manufactured. We prepared a production line at Keihin Product Operations in Yokohama and started production in 2015.

We have also received a contract for the design and manufacture of the mechanical equipment for the blanket remote handing system of ITER. This equipment is currently being designed, with the aim of commencing manufacturing in 2017.



Manufacturing of TF coil winding (upper) and structure segment (lower)

Completion of On-Site Assembly of JT-60SA Vacuum Vessel

The JT-60SA (JT-60 Super Advanced) experimental tokamak type thermonuclear fusion device is currently under construction by the National Institutes for Quantum and Radiological Science and Technology (QST) of Japan as a joint project between Japan and the EU. Since July 2014, Toshiba has been entrusted with the assembly of its vacuum vessel, one of the primary components needed to generate plasma.

The vacuum vessel is a torus-shaped structure consisting of nine sectors. Prior to welding, we made 3D measurements of their positions and shapes using a laser tracker. Based on these measurements, we then adjusted the welding conditions and procedures to minimize weld distortion. In addition, we adjusted the positions of adjacent sectors prior to welding, based on precise estimations of weld contraction. Splice plates were also inserted between sectors to adjust the final shape of the torus.

As a result, we have achieved an error of less than 10 mm from the design values for the position and shape of the torus, which measures approximately 6.6 m in height, 3.5 m in width, and 10 m in diameter. The welding and related work at the installation site was successfully completed on schedule in August 2015.

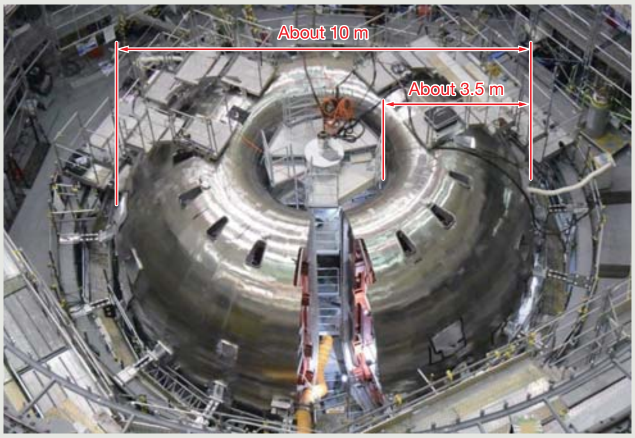


Photo courtesy of QST

Assembly of vacuum vessel for JT-60SA facility