

## Full Delivery of Steam Turbine Systems for New Nuclear Power Plants in U.S.A.

Toshiba has delivered four sets of 1 100 MWe steam turbines, generators, and main heat exchanger systems as planned for the AP1000™, Westinghouse Electric Company LLC's latest pressurized water reactor (PWR) under construction in the United States<sup>(\*)</sup>.

High performance of the turbines was achieved by optimizing the blade shape using three-dimensional (3D) design, and high reliability has been assured by the blade-cover coupling design. In addition, the turbines offer improved maintainability during operation due to the adoption of a common design for the turbine rotors in each stage.

We have established a worldwide network of 157 component suppliers for the manufacturing of nuclear steam turbine system equipment for the AP1000™ plants in the U.S. Together with Westinghouse, we will seek further opportunities to build AP1000™ nuclear power plants in the global market. We are promoting the ongoing development of turbine systems with high performance, high reliability, and improved maintainability, and are also pursuing the replacement of existing turbines in collaboration with Westinghouse.



Turbine rotor of AP1000™ for Vogtle Electric Generating Plant, U.S.A.

(\*) For Vogtle Electric Generating Plant Units 3 and 4 owned by Southern Company, and V.C. Summer Nuclear Station Units 2 and 3 owned by SCANA Corporation

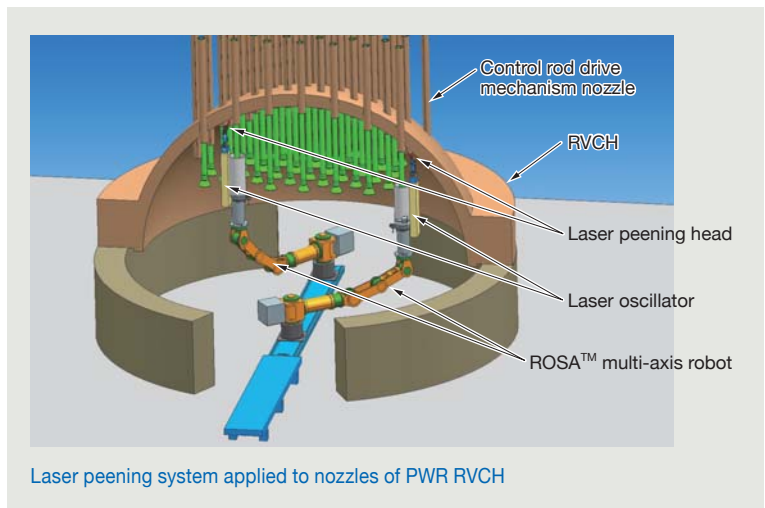
## Application of Laser Peening to PWRs in U.S.A.

Interest in peening for PWRs is increasing in the United States as a preventive maintenance measure for reactor vessel closure heads (RVCHs). Toshiba offers laser peening of RVCHs for stress improvement. Laser peening reduces the need for future repair and replacement of RVCHs and contributes to savings in plant maintenance costs.

Laser peening has been utilized underwater, as the inertia of water magnifies the plasma pressure that generates compressive stress on the material surface. Because an RVCH needs to be in the atmosphere during refueling, we developed a laser peening technology that utilizes a water shower in the air to achieve an effect equivalent to that of underwater laser peening.

One of the main advantages of laser peening is its process controllability. Since a laser is highly controllable, the laser peening process can be precisely monitored and is less susceptible to complex geometries of the peened product such as the shape of the RVCH nozzles. The laser peening process achieves accurate positioning in combination with a manipulator specifically designed for the RVCH. Additionally, the compact footprint of the laser peening heads makes it possible for the work to be performed in parallel, thereby minimizing the work duration.

Our laser peening technology has been successfully applied to a number of PWRs and boiling water reactors (BWRs) in Japan, and has also established a proven track record of reliability in the U.S. Furthermore, the Electric Power Research Institute Inc. (EPRI), a U.S. organization, has validated the effectiveness of our laser peening technology through testing.



Laser peening system applied to nozzles of PWR RVCH

## Overall Status of STP 3&4 Combined Construction and Operating License Application

In 2008, the U.S. South Texas Project Nuclear Operating Company (STPNOC) selected Toshiba's advanced boiling water reactor (ABWR) for Units 3 and 4 of the South Texas Project (STP 3&4) and submitted an application for a combined license (COL) to build and operate STP 3&4 to the U.S. Nuclear Regulatory Commission (NRC). Subsequently, the applicant for the STP 3&4 COL became Nuclear Innovation North America (NINA).

The NRC scrutinized the STP 3&4 COL application and issued a Request for Additional Information (RAI) to NINA regarding the design of this ABWR for the U.S. market (US-ABWR), antiterrorism measures, lessons learned from the Fukushima Daiichi nuclear accident, and so forth.

As the primary engineering, procurement, and construction (EPC) contractor for the project, Toshiba assisted NINA in responding to the RAI through direct explanations to and discussions with the NRC. As a result, the NRC completed the technical review of the STP 3&4 COL application in February 2015.

The next steps are the issuance of the Final Safety Evaluation Report (FSER) from the NRC's technical staff and a hearing process by the NRC Commission. The COL is expected to be issued by the beginning of 2016. Since the U.S. restarted planning for the construction of new nuclear power plants in 2007, COLs have been issued only for Westinghouse's four AP1000™ units as of the end of 2014.

Toshiba's US-ABWR is a revolutionary state-of-the-art BWR that satisfies the latest regulatory requirements in the U.S., including aircraft impact assessments and the lessons learned from the Fukushima Daiichi accident. Its design is based on the Japanese ABWR design, which has a well-proven track record of more than 15 years.



Overview of STP site

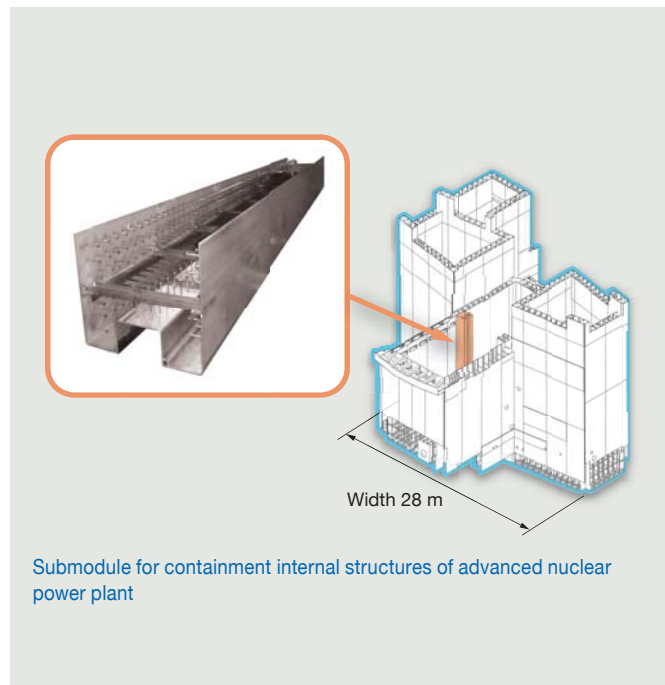
## Commencement of Submodule Fabrication for Containment Internal Structures of New U.S. Nuclear Power Plant

Toshiba is supplying submodules as components of the containment internal structures of the AP1000™ nuclear power plant, an advanced pressurized water reactor (PWR) being constructed by Westinghouse in the United States<sup>(\*)</sup>.

The containment internal structures incorporating a steel-plate-reinforced concrete structure form a large module structure, which houses main equipment such as the reactor vessel and steam generators. The module consists of approximately 40 submodules, which are being built at a dedicated production site of CB&I.

In order to weld multiple steel plates to fabricate a plate of 20 meters in overall length, our submodule requires high-level welding technology and highly accurate fabrication technology to limit the dimensional tolerance and deformation caused by welding distortion of the steel plates to 10 mm or less (1/2 000 of the overall length).

Through the use of our advanced fabrication technology, the first submodules were successfully completed in December 2014. We are now proceeding with fabrication of the next set of submodules to be shipped in 2015.



Submodule for containment internal structures of advanced nuclear power plant

(\*) For Southern Company's Vogtle Unit 4 and SCANA's V.C. Summer Unit 3

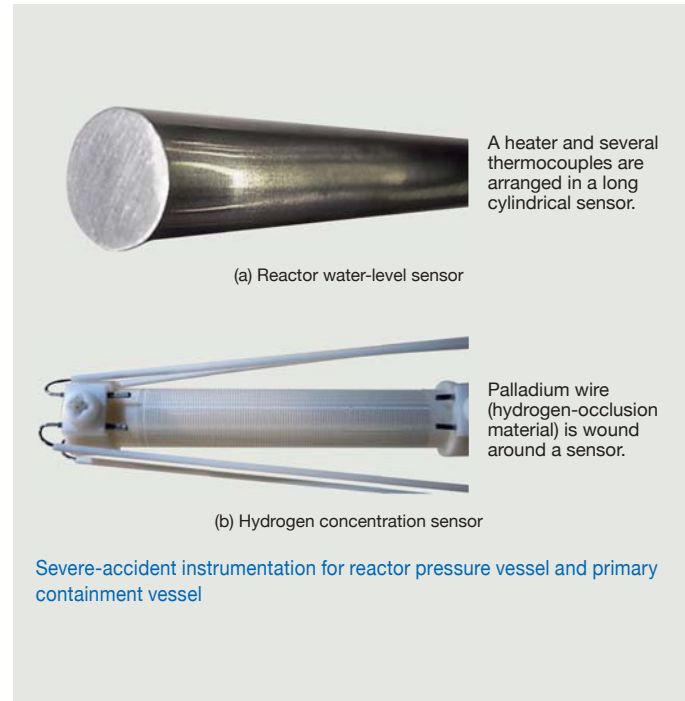
## Severe-Accident Instrumentation for Reactor Pressure Vessel and Primary Containment Vessel

Toshiba has developed new instruments for monitoring the water level in a reactor pressure vessel and the hydrogen concentration in a primary containment vessel in the event of a severe accident.

The reactor water-level instrument is a long cylindrical sensor in which a heater and several thermocouples are arranged along the axial direction. Its principle of measurement is based on the difference in thermal conductivity between water and air. The water level is calculated by heating the thermocouples and measuring the difference in the temperature increase.

The hydrogen concentration instrument is a tube type sensor incorporating a palladium wire. Its principle of measurement is based on the increase in electrical resistance of palladium caused by hydrogen occlusion. The hydrogen concentration is measured from the electrical resistance of the palladium wire.

The structures and measurement principles of these instruments are simple, and they can operate in a high-temperature, high-pressure, and high-radiation environment. We have conducted a number of experiments on the instruments that have demonstrated their high level of applicability under severe-accident conditions, and are planning to propose their adoption to customers.



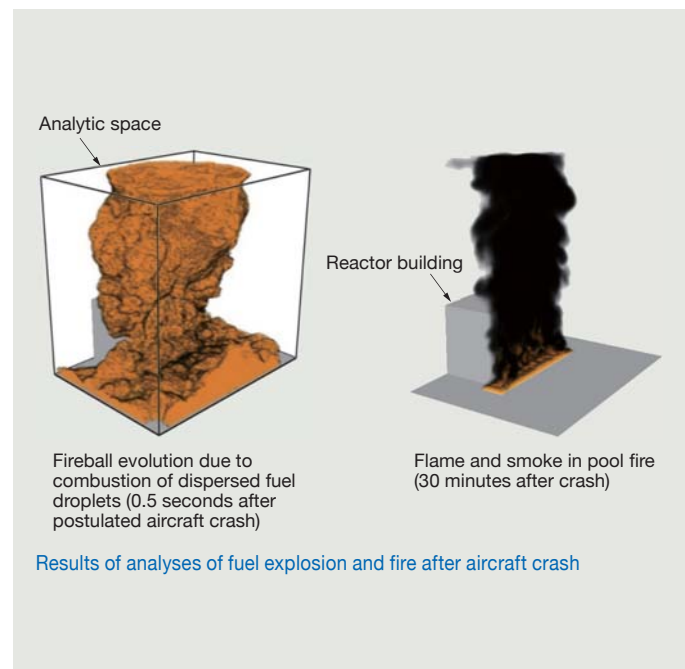
## Development of Simulation Technique for Fuel Explosion and Fire after Aircraft Crash to Further Enhance Safety Margins of Nuclear Power Plants

Under the new safety standards introduced after the Fukushima Daiichi nuclear accident, nuclear power plants are subject to a rigorous risk assessment for hazards, including an aircraft crash and natural disasters such as earthquakes and tsunamis.

One of the factors to be considered in the event of an aircraft crash onto a nuclear power plant is the fire caused by aircraft fuel carried in its fuel tanks. A technique for the simulation of aircraft fuel fires has therefore been required.

In response, Toshiba has developed a technique for simulating the evolution of a fireball caused by the combustion of dispersed fuel droplets in the air as well as the subsequent pool fire due to fuel drops that have fallen onto and accumulated on the ground, neither of which can be expressed by traditional methods for analyzing conventional fires.

The new simulation technique can estimate, in detail, transient changes in heat flux distribution due to thermal radiation and convection from flames to the facility buildings. The simulation shows possible damage to the buildings due to the effects of heat transfer from the fire. The results can be utilized to increase the safety of nuclear power plant buildings.





## Flat Core Catcher with High Thermal Conductivity

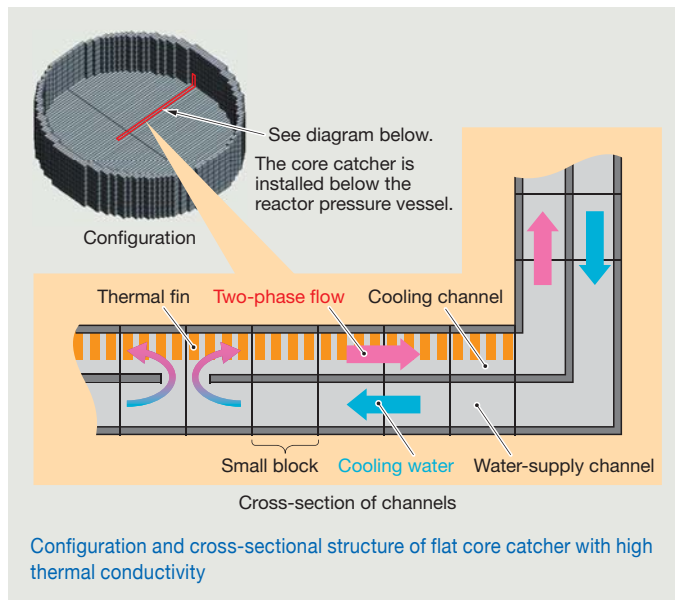
Toshiba has been developing a flat core catcher with high thermal conductivity to enhance the safety of nuclear reactors in the event of a severe accident. A core catcher is a device provided to catch and cool down molten core material.

A core catcher consists of a series of conjoined small block components, allowing it to be installed in a nuclear power plant with limited space. Each small block component is divided into two compartments for cooling and water-supply channels, respectively.

The cooling channel is equipped with thermal fins to cool the bottom surface of the molten core. We performed a flow visualization test on the cooling channel under the actual flow conditions of a nuclear power plant. From the test results, it was observed that water was supplied to the entire cooling channel due to the mixed flow of air and water. Thermal-structural integrity was also confirmed through heat conduction analysis.

Our next step is to conduct thermal hydraulic tests to further develop basic knowledge and technology for core catchers.

This research is partly sponsored by the “Infrastructure Development Project for Enhancement of Safety Measures at Nuclear Power Plants” of the Ministry of Economy, Trade and Industry.



## Technology for Manufacturing Reactor Core Material Using Silicon Carbide

Toshiba and Ibiden Co., Ltd. have established a manufacturing technology for a silicon carbide (SiC)-based material with outstanding heat and oxidation resistance, intended for reactor core applications in nuclear power plants. Toshiba and Ibiden have successfully utilized the new technology to create a prototype of a fuel assembly cover.

In order to enhance safety, the application of fiber-reinforced ceramic matrix composites to structural materials has been a focus of attention due to their effectiveness and their accident-tolerant properties, because the chemical and mechanical stability of such composites is significantly higher than that of metals at high temperatures.

The fuel assembly cover was manufactured using a composite SiC material that consists of continuous SiC fiber to provide reinforced strength. The new manufacturing technology achieves SiC layer formation at a speed approximately 20 times faster than the conventional method<sup>(\*)1)</sup> by using chemical vapor deposition (CVD)<sup>(\*)2)</sup>, as well as an optimized layer formation apparatus and process.

For data collection and verification purposes, Toshiba and Ibiden will begin the testing of the new fuel assembly cover in the future in a research reactor. The companies aim to put the cover into practical use by around 2025, as a replacement part for operating nuclear power plants.

Both companies have been collaborating with Nuclear Fuel Industries, Ltd., the University of Tokyo, and Tohoku University.

(\*)1) The new technology controls the temperature of only the film formation process and the source gas supply, whereas the conventional technology controls the temperature of the entire film formation apparatus and the source gas supply.

(\*)2) CVD is a chemical process used to deposit thin films on a substrate surface by introducing gases into a reaction chamber.



Prototype fuel assembly cover fabricated with SiC composite ceramics

## Toshiba's Technical Contributions to Decommissioning of TEPCO Fukushima Daiichi Nuclear Power Station

Toshiba's major contributions to the decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Co., Inc. (TEPCO) include the following:

First, in cooperation with Westinghouse, we have developed a remotely controlled system to be used to remove fuel from the Unit 3 spent fuel pool. This system is equipped with twin manipulators, to which various types of tools can be attached to make the fuel removal task accurate and efficient. At present, we are conducting shop tests for performance verification and training system operators.

Second, we have verified the applicability of a cosmic-ray muon technology for the imaging and mapping of nuclear fuel debris. The recovery team will use this technology to decide on debris retrieval methods by measuring the scattering behavior of muons. In addition, we have confirmed that a water-sealing material can be utilized in an underwater environment to stop leakage of the primary containment vessels and thereby achieve the submergence of fuel debris.

Finally, in response to the urgent need to remove radioactive species from wastewater stored at the site, we swiftly delivered original and enhanced versions of the multi-radionuclide removal system, a state-of-the-art system capable of removing 62 nuclides, as well as highly reliable storage tanks. Both of these facilities are currently in service for the treatment of radioactive wastewater.



Fuel removal system

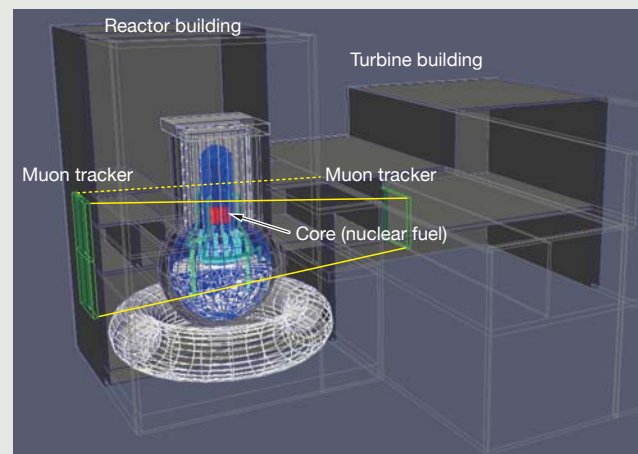
## Imaging of Nuclear Fuel Debris inside Fukushima Daiichi Nuclear Reactors Using Cosmic Muons

In order to remove uranium fuel from the damaged reactors of the Fukushima Daiichi Nuclear Power Station, it is necessary to estimate the locations and amounts of the nuclear fuel debris inside the reactor pressure vessels, which are inaccessible because of high radiation levels.

To address this problem, Toshiba has developed a debris imaging system in cooperation with the Los Alamos National Laboratory (LANL) in the United States, which measures the scattering of cosmic-ray muons outside the reactor building before and after they pass through the reactor core.

A technical demonstration using the Toshiba Nuclear Critical Assembly (NCA) has shown that the new system has high measurement sensitivity for uranium dioxide ( $\text{UO}_2$ ) and other heavy elements. Its spatial resolution for the imaging of nuclear fuel debris inside the reactor pressure vessel is expected to be approximately 30 cm under the current Fukushima Daiichi conditions.

We have also developed an essential component of the muon trackers with a detection area of  $7 \times 7$  m as well as electrical circuits that work in an environment with a high radiation level of 50 microsieverts per hour ( $\mu\text{Sv/h}$ ).



Visualization of core using muon trackers at Fukushima Daiichi Nuclear Power Station

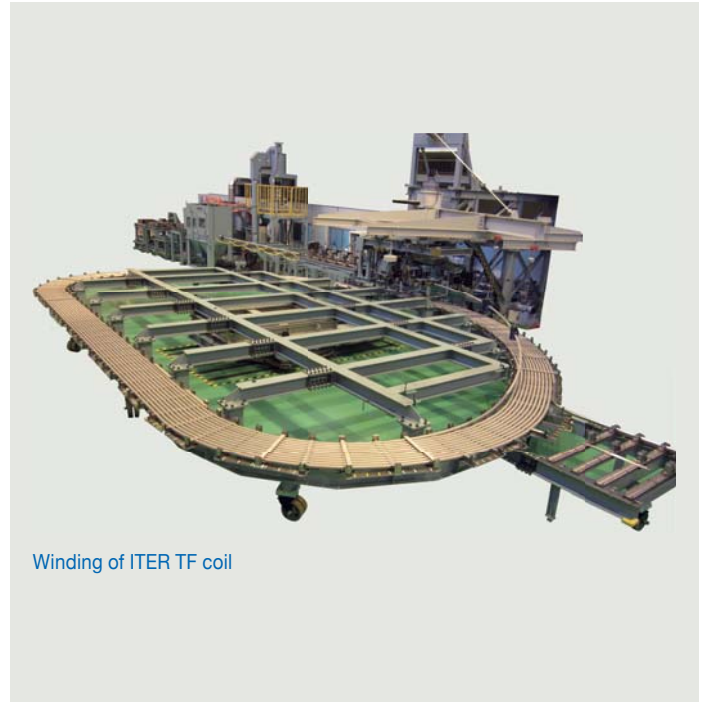
## Start of Manufacturing of Winding Packs for ITER TF Coils

ITER, which means “the way” in Latin, is an international project that aims to demonstrate the technological and scientific feasibility of fusion energy. ITER uses 18 toroidal field (TF) coils to produce magnetic fields that confine the high-temperature plasma needed to generate a fusion reaction. The TF coils, each 14 m in height, 9 m in width, and 300 tons in weight, are among the world’s largest D-shaped superconducting coils and generate a maximum magnetic field of 12 tesla.

Toshiba has received an order for four TF coils from the Japan Atomic Energy Agency (JAEA) out of the nine coils to be produced in Japan.

One TF coil uses a total of 4.6 km of superconductor strand, which is composed of 1 000 niobium-tin ( $\text{Nb}_3\text{Sn}$ ) wires with a diameter of 0.82 mm, twisted together and inserted into a stainless-steel protection tube of 43.7 mm in diameter and 2 mm in thickness.

We have developed a system for winding the superconductor into a D shape with a curvature tolerance of less than 2 mm while controlling the length tolerance within 0.01%, and commenced manufacturing of the TF coils.



Winding of ITER TF coil

## On-Site Assembly of JT-60SA Vacuum Vessel Using High-Precision Welding

The JT-60SA (JT-60 Super Advanced) experimental tokamak type thermonuclear fusion device is currently under construction by JAEA as a joint project between Japan and the European Union. The target of this project is to achieve an operating method that can maintain core plasma in the reactor for up to 100 seconds.

The vacuum vessel is one of the primary components of the JT-60SA to create the high vacuum conditions needed to generate plasma. The JT-60SA is a large torus-shaped structure, 10 m in diameter with double walls 18 mm thick. It is 6.6 m high, 3.5 m in width, and weighs a total of 150 tons. Due to its large size, Toshiba manufactured the vacuum vessel in 10 sectors. Each sector was further divided equally in the vertical direction from the center of the circle and then delivered to the site. We started assembling the vacuum vessel in July 2014.

Since a great deal of welding is involved in this assembly, we developed an automatic welding system to speed up construction. The system features a 3D object sensor to measure and position the surface to be welded. The position of each sector for welding of the vacuum vessel can be adjusted at a precision of 1 mm. With the use of this system in the project, assembly of the vacuum vessel has been proceeding on schedule.



Assembly of two 40-degree sectors of JT-60SA vacuum vessel



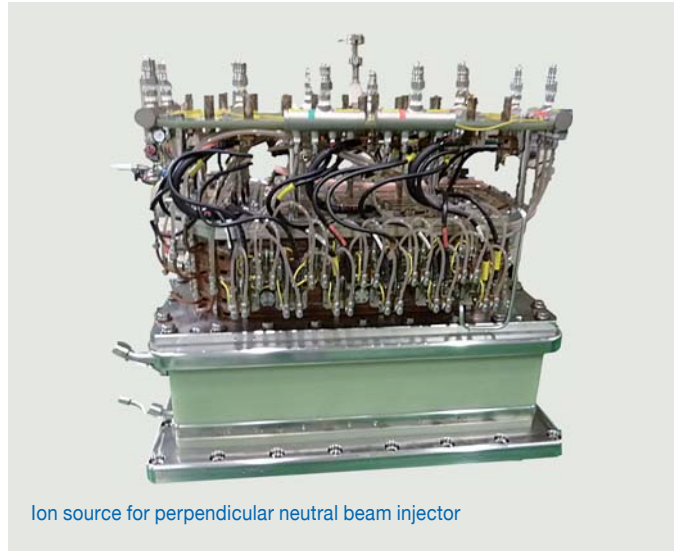
## Power Upgrade for Perpendicular Neutral Beam Injector of Large Helical Device

The National Institute for Fusion Science (NIFS) is a center for nuclear fusion research in Japan. NIFS has the Large Helical Device (LHD), one of the world's largest helical devices used to confine plasma with superconducting magnets.

Toshiba contributed to the achievement of an increase in the power of the perpendicular neutral beam injector, which is a primary device used to heat plasma for the LHD from 40 keV-6 MW to 60 keV-9 MW. We improved the power supplies used for beam acceleration and the four ion sources, which are key components needed to generate a beam. We released the upgraded version in September 2014.

The new ion sources have a 188 mA/cm<sup>2</sup> beam extraction current density and generate a highly convergent beam with a 1-degree angle of divergence. This delivers much higher plasma-injection beam energy in a beam having the same size as conventional ion sources. When an electrical breakdown occurs between grids of ion sources, existing 40 kVDC power supplies and additional 20 kVDC power supplies must interrupt the breakdown current simultaneously. The new power supplies deliver the level of advanced synchronized power control required.

By upgrading the core device for the LHD, we are supporting the remarkable progress of plasma physics research in the field of nuclear fusion power generation.



Ion source for perpendicular neutral beam injector

## Replacement of Major Control Systems with Digital Systems

Westinghouse has successfully designed and commissioned multiple nuclear steam supply systems (NSSS) and electrohydraulic control (EHC) systems using the Ovation<sup>®</sup> distributed control system (DCS), to assist utilities in deploying advanced automation and in some cases increasing power production. Westinghouse successfully upgraded the NSSS systems at Duke Energy Corporation's Catawba and McGuire nuclear stations between 2010 and 2012. These upgrades have allowed Duke Energy to achieve an increase in power generation. Westinghouse has also worked with Exelon Generation Company LLC to upgrade its analog EHC systems at Limerick Generating Station Units 1 and 2 (2014 and 2015). These control system upgrades were carefully planned and successfully installed during normal outage schedules.

Westinghouse designs these systems to provide a reliability of greater than 99.99%, striving to eliminate all single point vulnerabilities (SPVs) in the control process. A plant computer model is used in a closed control loop with the control system to validate the responses of both the relevant plant processes and the control system designs of interest, thereby enhancing plant reliability.

Westinghouse is working with Exelon Generation to upgrade the NSSS systems at the Braidwood and Byron generating stations, and the EHC systems at Peach Bottom Atomic Power Station Units 2 and 3. Installation of these systems will take place between 2016 and 2020.

*Ovation is a registered trademark of Emerson Process Management.*



Ovation<sup>®</sup> NSSS cabinet for McGuire Nuclear Station on factory floor

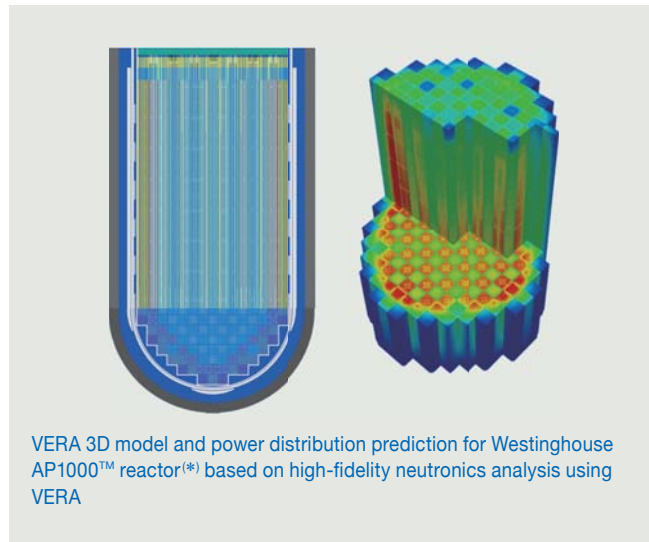
## Advanced Safety Analysis Methods through CASL

The Consortium for Advanced Simulation of Light Water Reactors (CASL) is an Energy Innovation Hub established by the U.S. Department of Energy in 2010 to advance the development and application of modeling and simulation technologies for nuclear reactors. CASL's mission is to "provide coupled, higher-fidelity, usable modeling and simulation capabilities needed to address light water reactor operational and safety performance-defining phenomena."

By leveraging state-of-the-art software techniques and computer platforms, CASL experts from national laboratories, universities, and industry are developing and deploying CASL's Virtual Environment for Reactor Applications (VERA), a "virtual reactor" designed to accurately simulate the physical processes inside a reactor at unprecedented levels of detail. These processes include neutron transport, thermal hydraulics, nuclear fuel performance, and corrosion and surface chemistry.

VERA is being developed with Department of Energy funding over a period of 10 years. Westinghouse is a key industry partner in CASL, as a source of industrial leadership in the development of advanced products and services that create long-lasting value for customers and Toshiba. VERA has already provided benefits by generating high-fidelity predictions to benchmark our tools for the AP1000™ reactor startup and for conducting plant fuel analyses, and will be used for risk assessments and safety analysis applications.

(\*) Westinghouse's AP1000™ "Generation 3+" reactor design is the basis for eight reactors now under construction.

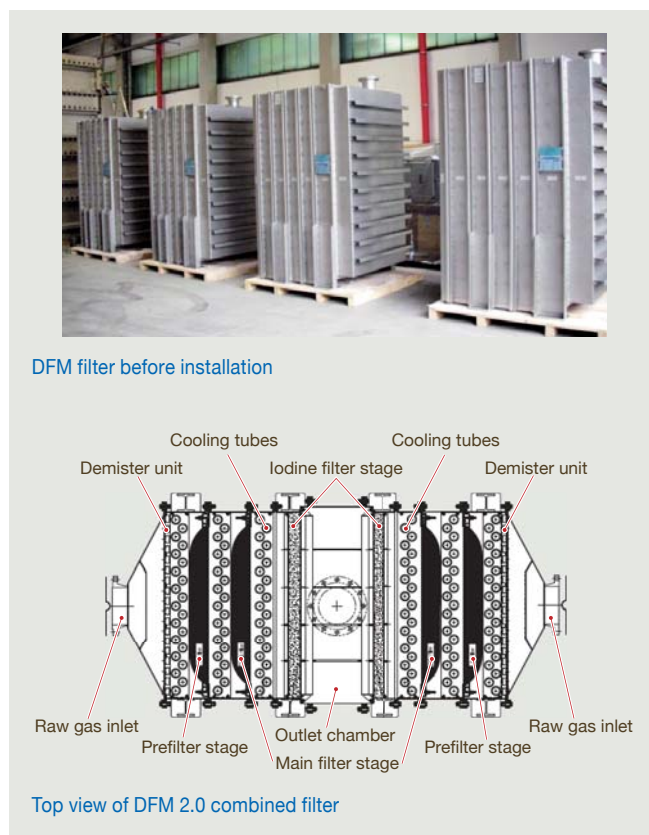


## Development of Dry Filter Method for Containment Filtered Vent Systems

Westinghouse has continued to develop its dry filter method (DFM) to be implemented in containment filtered vent systems (CFVS) in order to bring innovative technology to both existing and new customers.

A solution was developed for the PWR fleet of a Japanese electric power company in order to eliminate all risks of hydrogen burns inside the system in the event of a severe accident. Qualification testing was performed for this new technology, in which flammable gases are recombined within the DFM by means of pellets coated with palladium inside the aerosol filters.

Another technological advancement was achieved with the qualification testing of the so-called DFM 2.0. In this new technology, zeolite is inserted inside the aerosol filters to be located inside the containment vessel. This brings significant advantages to our customers since this new type of filter is designed to retain all fission products inside the containment vessel while decreasing the amount of hardware and engineering required, thereby reducing capital investment. DFM 2.0 has helped Westinghouse to maintain market leadership in the CFVS business.





## Westinghouse Accident-Tolerant Fuel Program

The Westinghouse approach to the development of accident-tolerant fuels (ATFs) has focused on both cladding and fuel pellet options. When coupled together, these will be economically attractive to utility customers. They can be more tolerant than their designed basis against accidents such as Fukushima. Coatings on zirconium alloy tubing and SiC-based cladding are the two cladding variants that have been selected to provide a range of options to suit different implementation timetables. Uranium silicide ( $U_3Si_2$ )- and uranium nitride (UN)-based pellet designs, which offer significant increases in thermal conductivity and more advantageous fuel economics in comparison with uranium dioxide ( $UO_2$ ), have been selected as options for the fuel pellet design.

The Westinghouse program is funded mainly through the U.S. Department of Energy, and includes many partners. Significant progress has been made to date, with the fabrication of coated cladding samples, one-meter-long SiC tubes, and both  $U_3Si_2$  and UN pellets. Testing is ongoing in the test reactors as well as in autoclaves. Over the next two years, the program will culminate in the manufacture of fuel rods that will undergo a six-year exposure in test reactors as a prelude to the loading of lead test rods in commercial reactors by 2022.



Samples of one-meter-long SiC tubes

## Start of Commercial Operation of Kashima Thermal Power Station Group 7 of TEPCO and Hachinohe Thermal Power Station Unit 5 of Tohoku Electric Power Co., Inc.

Toshiba constructed two simple-cycle power plants, Kashima Thermal Power Station Group 7 of TEPCO and Hachinohe Thermal Power Station Unit 5 of Tohoku Electric Power Co., Inc., in order to ease the tight power supply situation in the wake of the Great East Japan Earthquake. Both of these power plants achieved commercial operation in July 2012.

The construction work began immediately after the earthquake, and commercial operation was successfully inaugurated in only 16 months.

We subsequently continued with construction work to convert the two simple-cycle power plants into combined-cycle plants and achieved commercial operation approximately two years after the completion of the simple-cycle facilities: in June 2014 for Kashima Thermal Power Station Group 7 and August 2014 for Hachinohe Thermal Power Station Unit 5.

The manufacturing of the necessary equipment and the commissioning of both the simple- and combined-cycle power plants were therefore successfully completed in an extremely short period.

Kashima Thermal Power Station Group 7 consists of three gas-fired units with a power output of 420 MW each. Hachinohe Thermal Power Station Unit 5 originally consisted of one distillate oil-fired unit with a power output of 394 MW, which was converted to a gas-fired unit with a power of 416 MW in July 2015.



Kashima Thermal Power Station Group 7 of TEPCO



Hachinohe Thermal Power Station Unit 5 of Tohoku Electric Power Co., Inc.

## Shipment of Steam Turbines for Kudgi Super Thermal Power Plant Units 1, 2, and 3, India

Toshiba was awarded a contract in February 2012 by NTPC Limited, India, to supply steam turbines for Units 1, 2, and 3 of the coal-fired Kudgi Super Thermal Power Plant, and completed their delivery in May 2015.

This contract was the first project for which Toshiba JSW Power Systems Pvt. Ltd. (Toshiba JSW), Toshiba's manufacturing and engineering base in India, conducted engineering, procurement, manufacturing, installation, and erection work.

Toshiba JSW and Toshiba cooperated throughout the project. Toshiba designed all of the units and manufactured the turbine rotors for Unit 1, and Toshiba JSW manufactured the turbine casings, nozzles, and other components for all of the units. Toshiba dispatched technical advisors for installation and commissioning supervisors to the Kudgi site to give advice.

In the future, Toshiba JSW will play the main role in expanding our business activities in India, where the market is growing rapidly, as well as in Southeast Asia, the Middle East, and Africa, where electricity demand is expected to increase.



Intermediate-pressure turbine rotor for Kudgi Super Thermal Power Plant Unit 1, India



Low-pressure turbine rotor for Kudgi Super Thermal Power Plant Unit 1, India

## Turbine Retrofit and Generator Stator Rewind at Ottumwa Generating Station, U.S.A.

Toshiba International Corporation in the United States was awarded a turnkey project contract to retrofit the steam path on all four turbine sections (high-pressure, intermediate-pressure, low-pressure A, and low-pressure B) of a General Electric G3 steam turbine with Toshiba's new components, and to rewind a hydrogen and water-cooled generator coil, at the Ottumwa Generating Station, U.S.A.

During the preparation work, we implemented several measures to save lead time such as installing nozzle diaphragms into the inner casing prior to the retrofitting work. As a result, the project was completed two days earlier than the contracted date. Furthermore, the power output was increased from 674 MW to 792 MW.



High-pressure turbine rotor for Ottumwa Generating Station, U.S.A.

## AX Series Standardized Turbine Island System for Thermal Power Plants

The AX series is a range of standardized turbine island systems for conventional thermal power plants. The system consists of a steam turbine, generator, heat exchangers, and auxiliary systems, which together are commonly referred to as a turbine island. As one of the world's leading suppliers of steam turbines and generators that serve as the core of a turbine island and that define its performance and reliability, Toshiba has optimized and developed new standardized turbine island systems.

The AX series realizes higher quality and shortens the periods required for engineering, manufacturing, procurement, and construction of the power plant. The range of the AX series is classified according to the output power, with systems for outputs of 1 000 MW (AX1000), 650 MW (AX650), and 300 MW (AX300). The system design of the AX1000 focuses on high efficiency and reliability for power plants with a large base load. In addition to the standard system, options are available in the AX series to build a configuration in accordance with the customer's specific requirements and allow for more flexibility.

The AX1000 series was applied for the first time at the Jimah East Power Plant, an ultra-supercritical coal-fired power plant in Malaysia (1 000 MW x two units), for which we received the contract in September 2014 and started construction thereafter.



AX1000 1 000 MW-class standardized turbine island system for thermal power plants

## Total Number of Orders for Steam Turbine Generators in North American Market Reaches 100

Toshiba's sales of steam turbine generators (STGs) in the North American market have been rising steadily since the late 1990s. In August and December 2014, the Thomas C. Ferguson Power Plant in Texas (195.1 MW STG) and the Ninemile Point Power Plant Unit 6 in Louisiana (241.4 MW STG) respectively entered commercial operation on schedule.

Additionally, we received orders for four new STGs in 2014: for the Paradise Fossil Plant in Kentucky (322.7 MW STG), the York 2 Energy Center in Pennsylvania (354.2 MW STG), the Eagle Valley Generating Station in Indiana (263 MW STG), and the Allen Fossil Plant in Tennessee (470 MW STG). With these orders, the cumulative number of orders for STGs in North America has reached 100.

Toshiba will continue to introduce products that meet the specific needs of the market.



STG for Thomas C. Ferguson Power Plant, U.S.A.



## Application of Control Systems Using TOSMAP-DS™ /LX to Thermal Power Plants

Toshiba has successfully applied distributed control systems (DCS) equipped with the new-generation TOSMAP-DS™/LX controller to unit monitoring and control in combined-cycle power plants (Amata B. Grimm Power ABP4 and ABP5 power plants, Thailand; 120 MW each). The new-generation controller has also been applied to the electrohydraulic control (EHC) system for steam turbine governing and monitoring at a coal-fired power plant (Point Aconi Generating Station Unit 1, Canada; 184 MW).

TOSMAP-DS™/LX is a new addition to the Toshiba Microprocessor Aided Power system control - DynaStream (TOSMAP-DS™) series, which provides a full range of sophisticated control and monitoring capabilities for an entire plant.

TOSMAP-DS™/LX is based on our proprietary technology in the power generation control field combined with generic computer technology. Its controller modules are easily mountable, making it possible to build a compact DCS. Furthermore, since TOSMAP-DS™/LX is compatible with various fieldbus network interfaces, it contributes to significant reductions in the number of signal cables and the system manufacturing period as well as to improved system maintainability and extensibility.

TOSMAP-DS™/LX provides special interface modules for high-speed EHC and an automatic voltage regulator (AVR) for turbine generator excitation control and monitoring, as well as the basic components for a DCS. Thus, it allows the construction of a total power plant control system including the DCS, EHC, and AVR.



TOSMAP-DS™/LX controller for combined-cycle power plant control systems at Amata B. Grimm Power ABP4 and ABP5 power plants, Thailand

## Completion of Partial Upgrade of Control System for Fong Der Thermal Power Station Unit 2, Taiwan

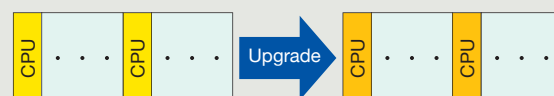
Toshiba successfully completed a project to upgrade the control system for Unit 2 of the Fong Der Thermal Power Station in May 2014, concluding the last of three similar projects in Taiwan (Fong Der Units 1 and 2, and Chang Bin Thermal Power Station).

In the Fong Der Unit 2 project we replaced the total control system, consisting of a DCS for plant control, an EHC system for turbine control, and an AVR for generator control, with controllers of the TOSMAP-DS™/ev series.

We implemented the following measures to minimize on-site modification and inspection work, extend the system life cycle, and add new functions:

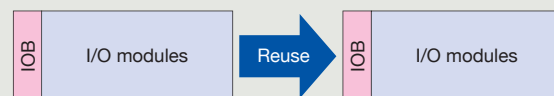
- The input and output (I/O) modules and external cables were reused.
- The controller modules and the human-machine interface were replaced with the latest models.

By optimizing the on-site work plan, we were able to reduce on-site work hours by 36% compared with the previous project.



Upgrade to latest controller (CPU modules)

Reuse of existing modules (I/O modules)



CPU: central processing unit module I/OB: I/O buffer module

Partial upgrade of control system for Fong Der Thermal Power Station Unit 2, Taiwan

## Major Overhaul of Pump-Turbine and Generator-Motor and Commencement of Commercial Operation Test at Ludington Pumped Storage Plant, U.S.A.

The Toshiba Group successfully completed the commissioning test of the first unit (Unit 2) of the Ludington Pumped Storage Plant, owned by Consumers Energy and DTE Energy Electric Company, in March 2015 after a major overhaul. The unit was temporarily handed over to Consumers Energy and DTE Energy and will be finally accepted upon completion of a commercial operation test.

In January 2011, Toshiba International Corporation in the United States was awarded a contract for this project to refurbish one of the largest pumped-storage plants in the world. The Toshiba Group supplied pump-turbine runners, generator-motor stators, thrust bearings, circuit breakers, and static excitation systems for all six units of the plant, and implemented the refurbishment of reused components as well as installation and commissioning. The pump-turbine runners, stator frames, and some other components were manufactured by Toshiba Hydro Power (Hangzhou) Co., Ltd. in China.

The pump-turbine runner is one of the largest in the world<sup>(\*)</sup>, approximately 270 tons in weight and 8.4 m in outside diameter.

Despite the lack of original equipment manufacturer (OEM) information for the existing units, we were able to successfully carry out the design, manufacturing, and installation tasks in cooperation with Consumers Energy and DTE Energy.

The ratings of the main components are as follows:

- Pump-turbine: 359 MW/398 MW-98/111 m-112.5 min<sup>-1</sup>
- Generator-motor: 455 MVA/455 MVA-20.0 kV-112.5 min<sup>-1</sup>-60 Hz.

(\*) As of February 2015 (as researched by Toshiba)



Ludington Pumped Storage Plant of Consumers Energy and DTE Energy Electric Company, U.S.A.

## High-Speed, Large-Capacity, Adjustable-Speed Pumped-Storage Systems Enter Commercial Operation

Kazunogawa Pumped Storage Power Station Unit 4 of TEPCO and Kyogoku Pumped Storage Power Station Unit 1 of Hokkaido Electric Power Co., Inc. (HEPCO) respectively entered commercial operation in June and October 2014.

Both units are adjustable-speed pumped-storage systems featuring an adjustable pump input and a wide turbine output range. Kazunogawa Unit 4 has an adjustable turbine output range of 270 MW between 130 MW and 400 MW. This is approximately double the range of Units 1 and 2, which are conventional pumped-storage systems in the same powerhouse. The turbine output of Kyogoku Unit 1 is adjustable between 0 MW and approximately 200 MW.

Furthermore, Kyogoku Unit 1 is equipped with a flywheel mode, which helps to reduce grid frequency fluctuations caused by fluctuations in photovoltaic and wind power generation.

Kazunogawa Unit 4 has the world's highest pumping head of 785 m for single-stage pump turbines<sup>(\*)</sup> and the world's largest capacity of 475 MVA for adjustable-speed pumped-storage systems<sup>(\*)</sup>.

The ratings of the main components of each unit are as follows:

1. Kazunogawa Unit 4
  - Pump turbine: 412/460 MW-728/785 m-500 min<sup>-1</sup>±4%
  - Generator-motor: 475 MVA/460 MW-18 kV-50 Hz-500 min<sup>-1</sup>±4%
2. Kyogoku Unit 1
  - Pump turbine: 208/230 MW-414.2/436.5 m-500 min<sup>-1</sup>±5%
  - Generator-motor: 230 MVA/230 MW-16.5 kV-50 Hz-500 min<sup>-1</sup>±5%.

(\*) As of February 2015 (as researched by Toshiba)



Kazunogawa Pumped Storage Power Station of TEPCO



Kyogoku Pumped Storage Power Station of HEPCO

## Start of Commercial Operation of High-Head Bulb Turbines and Generators with China's Largest Capacity at Huangfeng Hydropower Station

All five units of the horizontal bulb type turbines and generators supplied by Toshiba Hydro Power (Hangzhou) Co., Ltd. (THPC) for the Huangfeng Hydropower Station in China's Qinghai Province commenced commercial operation in August 2014.

Toshiba was awarded a contract for this project in July 2007. Toshiba developed the hydraulic design of the turbine utilizing computational fluid dynamics (CFD), and THPC tested the turbine model, developed the structural design including the generator electrical design, and manufactured all of the units.

The maximum head of 19.1 m and maximum unit output of 45 MW are both the largest ever recorded in China for a bulb type turbine/generator(\*). This high-head bulb turbine incorporates a four-blade runner.

At the beginning of commercial operation, the turbine had to operate at a low head of around 8 m due to the water level in the upstream reservoir, but it was verified that the turbine can be operated without problems even at such a low head.

The ratings of the turbine and generator are as follows:

- Turbine: 45.92 MW-16 m-115.4 min<sup>-1</sup>
- Generator: 47.368 MVA-13.8 kV-115.4 min<sup>-1</sup>-50 Hz.

(\*) As of February 2015 (as researched by Toshiba)



Runner assembly at site of Huangfeng Hydropower Station, China

## Commencement of Commercial Operation of Sogamoso Hydroelectric Power Plant, Colombia

The Sogamoso Hydroelectric Power Plant owned by ISAGEN S.A. E.S.P. started commercial operation in December 2014. The newly constructed hydroelectric power plant is located in Santander Department in northern Colombia. The total output of the plant is 820 MW, meeting 8.3% of Colombia's total electricity demand.

Toshiba has supplied the hydro generators for the plant, which have a single-unit capacity of 324 MVA, the largest in Colombia(\*), as well as auxiliary equipment and supervision services for on-site construction since being awarded the contract for this work in February 2010. We have supplied more than 30 hydro generators in Colombia over the past 30 years, catering to the demand for electricity in this country.

The ratings of the hydro generators for the Sogamoso Hydroelectric Power Plant are as follows:

324 MVA-16.5 kV-163.63 min<sup>-1</sup>-60 Hz × 3 units.

(\*) As of December 2014 (as researched by Toshiba)



Generator rotor for Sogamoso Hydroelectric Power Plant, Colombia



## Commencement of Commercial Operation of Patuha and Olkaria Geothermal Power Plants in Indonesia and Kenya

The Patuha Geothermal Power Plant in Indonesia (55 MW  $\times$  1 unit) and the Olkaria Geothermal Power Plant in Kenya (70 MW  $\times$  4 units) commenced commercial operation in October 2014 and January 2015, respectively. Toshiba supplied the main power generation equipment for both power plants and was responsible for its installation and commissioning.

These were the first geothermal power plant projects in which we were involved in Indonesia and Kenya. In response to the recent active development of geothermal power generation in these countries, we will continue to contribute to their geothermal power plant projects.

The details of the main equipment supplied to the two power plants are as follows:

1. Patuha Geothermal Power Plant
  - Steam turbine: Single casing, single flow, axial-flow exhaust
  - Condenser: Direct cooling spray
  - Generator: Three-phase, horizontal shaft, cylindrical casing, rotating magnetic field
2. Olkaria Geothermal Power Plant
  - Steam turbine: Double casing, double flow, downflow exhaust
  - Generator: Three-phase, horizontal shaft, cylindrical casing, rotating magnetic field.



Patuha Geothermal Power Plant Unit 1, Indonesia



Geothermal Power Plant, Kenya

## Completion of Steam Turbine Retrofit Project at Bacman Geothermal Power Plant Units 1 and 2, Philippines

The steam turbine retrofit project for the Bacman Geothermal Power Plant in the Philippines was completed in October 2014 for Unit 2 and February 2015 for Unit 1. The original main steam path components of the turbine (rotor and nozzle diaphragms) provided by another manufacturer were replaced with Toshiba's newly designed components through this project.

First, the existing turbine components were measured at the power station. Based on the measurement data, we designed and manufactured the new steam path components applying our sophisticated technologies to ensure better performance and higher reliability.

The components were installed by one of Toshiba's subsidiary companies and the work was completed successfully ahead of schedule. Both units are now operating safely with excellent performance.

We will continue to work on similar geothermal turbine retrofit projects to enable our customers to utilize geothermal energy more efficiently and reliably.



Turbine rotor for Bacman Geothermal Power Plant Unit 2, Philippines

## Commencement of Operation of 420 kV-80 kA Gas-Insulated Switchgear for Al-Zour North "Z" 400/300 kV Substation, Kuwait

The Al-Zour North "Z" 400/300 kV Substation, for which Toshiba was awarded a full turnkey contract by the Ministry of Electricity and Water (MEW) of Kuwait in September 2012, successfully commenced operation in February 2015 after being partially energized in May 2014. Consequently, the Az-Zour South Power Plant has started to transmit electricity through this substation.

Kuwait faces a number of serious problems regarding its power grid, including insufficient power generation and transmission capacities. In this situation, the MEW has been focusing on augmenting its power facilities. In particular, there are plans to increase power generation facilities in order to provide a total capacity of 6 500 MW in the Az-Zour area. The existing transmission system was considered to be insufficient to accommodate the rated short-circuit capacity of 63 kA. To avoid this problem, the MEW planned to build a new substation with a short-circuit capacity of 80 kA, the first in Kuwait and the Middle East<sup>(\*)</sup>.

Toshiba developed and installed the 420 kV-80 kA gas-insulated switchgear (GIS) used in this substation, which provides a solution for a short-circuit capacity exceeding 63 kA. This GIS is expected to contribute to stabilization of power supply systems in various countries of the world in the future.

(\*) As of July 2010 (as researched by Toshiba)



420 kV-80 kA GIS for Al-Zour North "Z" 400/300 kV Substation, Kuwait

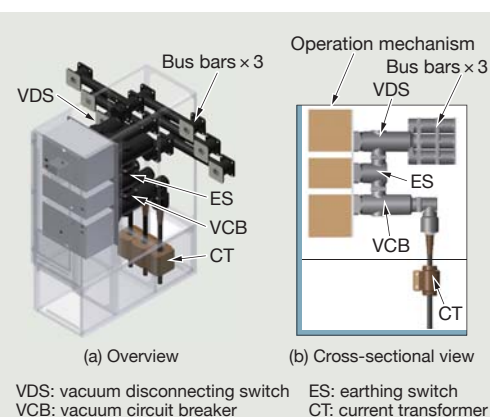
## 36/40.5 kV Solid-Insulated Switchgears for Global Distribution Market

Toshiba has developed 36 and 40.5 kV solid-insulated switchgears (SIS) that are compliant with both the International Electrotechnical Commission (IEC) and Chinese Guo Biao (GB) standards. It is common to use a cubicle type GIS (C-GIS) employing sulfur hexafluoride (SF<sub>6</sub>) gas as an insulation medium in medium-voltage distribution systems. Although the compactness of a C-GIS using SF<sub>6</sub> is a significant advantage, demand has been increasing for SF<sub>6</sub> gas-free products in recent years. The SIS can meet such demand and realize a safe and compact system due to its excellent technical features.

All of the main energized parts of our newly developed 36 and 40.5 kV SIS products are molded and insulated by a unique epoxy resin, and the surfaces of these molded parts are grounded. As a result, the 3-phase energized parts are separated completely, and the possibility of an internal arc accident is greatly minimized. Our unique epoxy resin having a high insulation capacity realizes an SIS that is smaller and lighter than a conventional C-GIS.

The 36 kV SIS, whose ratings are 1 250 A-31.5 kA, has been certified by a third-party test laboratory as compliant with both the IEC and European Norm (EN) standards. We also plan to apply for GB and American National Standards Institute (ANSI) certifications of this SIS.

We intend to supply SIS products to the global market through our manufacturing and supply bases around the world with the aim of contributing to the expansion of greenhouse-gas-free electricity distribution systems.



3D model of SIS



SIS undergoing certification test at Centro Elettrotecnico Sperimentale Italiano (CESI)

## 17.5 kV Vacuum Circuit Breaker Series Equipped with Molded Vacuum Interrupter for Electricity Distribution Systems

Toshiba has developed a new vacuum circuit breaker (VCB) series that is compact and economical, for use in electricity distribution systems compliant with the IEC standards.

In order to develop a small VCB, we adopted a molded vacuum interrupter to minimize the insulation distance of the main circuit. Moreover, to realize a low product price, we reduced the manufacturing costs by utilizing our worldwide procurement network including low-cost countries and carrying out manufacturing at our local production sites.

This VCB series complies with the IEC standards. We have also ensured the compatibility of this series with similar products of competitors, without eroding the quality and functionality. We plan to further strengthen our capability for retrofit refurbishment of aged VCBs with our new VCBs that are highly reliable and reasonably priced.



17.5 kV VCB equipped with molded vacuum interrupter

## Polycrystalline Silicon PV Module for Industrial PV Generation Systems

Toshiba developed a 250 W polycrystalline silicon photovoltaic (PV) module for industrial use and released it in July 2014.

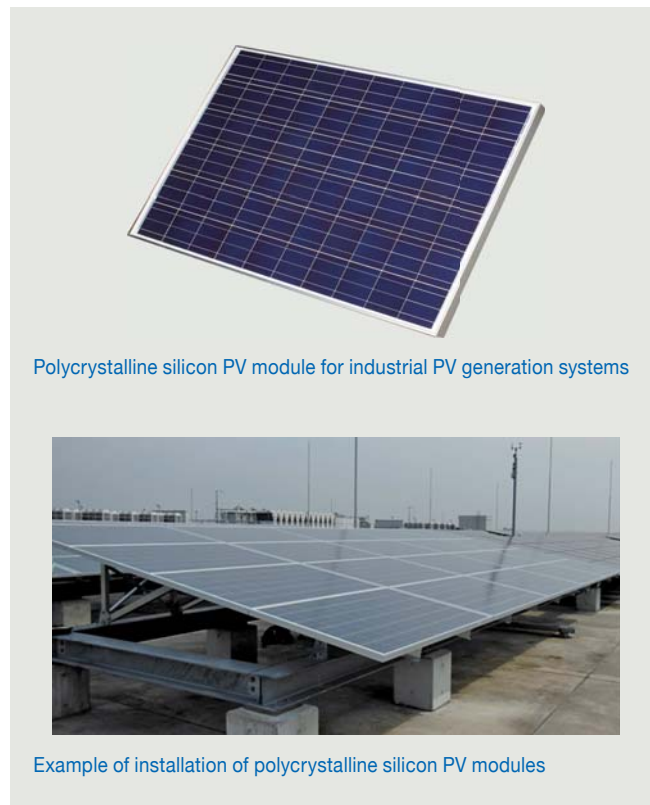
Industrial PV systems are generally expected to operate for more than 20 years. To meet this requirement for long-term serviceability, we have established original quality criteria and a reliability assurance scheme.

We performed several reliability tests under more stringent conditions than those set forth in the IEC standards, including the damp heat test, salt mist corrosion test, and potential induced degradation (PID) test.

The new PV module received JETPVm certification from the Japan Electrical Safety & Environment Technology Laboratories (JET) in March 2015, as well as certification for reliability under Japanese Industrial Standard (JIS) Q 8901(\*).

We released the new PV module in the European market in April 2015 and are planning to market it in Asia and other regions. We will promote its superior quality and reliability features to appeal to various domestic and overseas customers.

(\*) Terrestrial photovoltaic (PV) modules—Requirement for reliability assurance system (design, production and product warranty)



Polycrystalline silicon PV module for industrial PV generation systems

Example of installation of polycrystalline silicon PV modules