FY2017 Annual Report

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FY2017 Annual Report

CRIEPI

CRIEPI
Central Research Institute of Electric Power Industry

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Overview of the FY2017 Annual Report

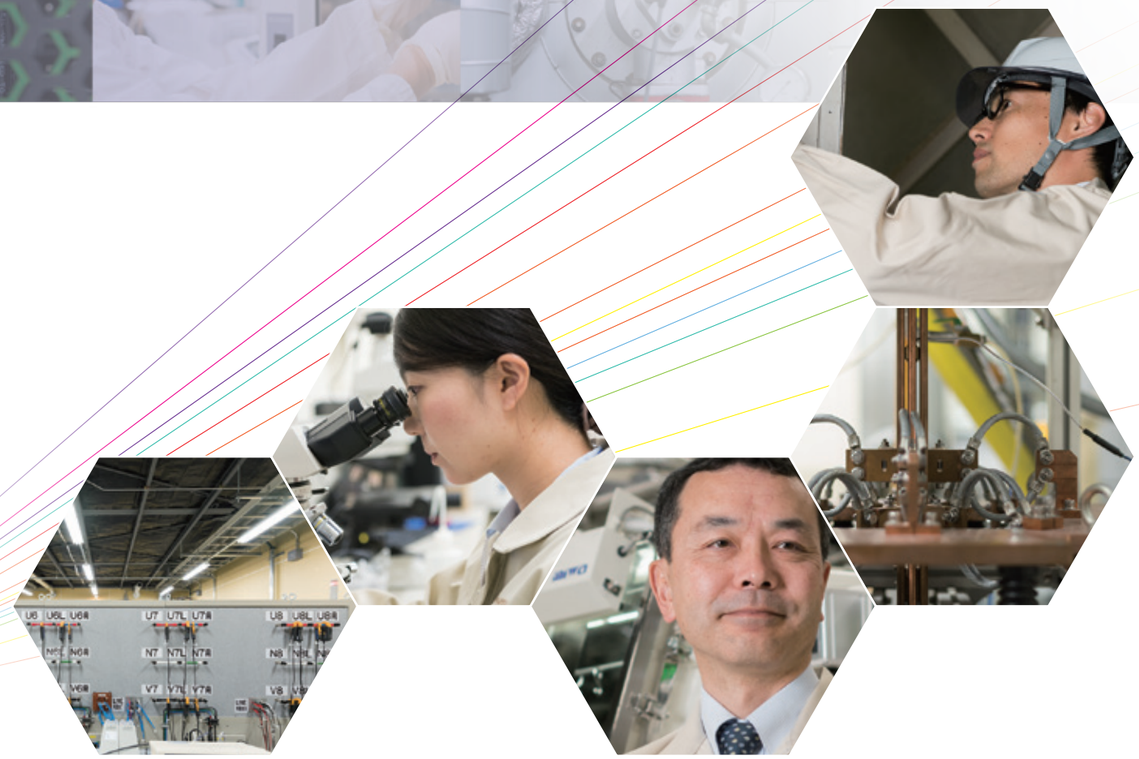
Electric power companies have recently started to apply risk information to autonomous and successive improvement of the safety in nuclear power generation. They are expected to provide stable power supply service economically even under the current situation that large-scale natural disasters occur frequently and electric power demand is saturating. In addition, customers even ask for new and interesting values to the electricity in accordance with the diversification of their preferences and life styles.

CRIEPI engages in research and development activities with consideration to these circumstances and has produced the following results. In the nuclear power generation field, we have produced several results contributing to the improvement of safety against low-frequency events as one of the pieces of Probabilistic Risk Assessment. We have also produced results supporting supply/demand coordination at higher level in accordance with increasing dispersed power generation and progressing digital technology, as well as offering new customer services aimed at the promotion of electrification. Moreover, we have developed technologies utilizing AI, etc. which contribute to reasonable maintenance and management of aging electric power facilities.

On the other hand, we believe that energy system reforms is inevitable to sustain safe and economical supply and usage of electric power, in response to the international trend towards accelerating decarbonization. To lead the way in such reforms, we have clarified the technological challenges and formulated mid-to-long term research strategy towards finding solutions to such issues.

Our mission to support electric power industry as the leading research institute through technology development remains unchanged under the ever- changing environment surrounding the electric power industry. Considering future changes in the society and technology, we continuously contribute to the electric power industry and to the society by creating and offering reliable values grounded in scientific objectivity through the integrated knowledge and efforts of our researchers in various expertise.

Masahiro Kakumu
President



CRIEPI, as the “central research institute of the electric power industry” and “academic research institute contributing to society through scientific technology research”, will support reform of technologies and systems relating to the supply and usage of energy, including electric power, and continue to guide the energy industry forward.

1. Outline of Business Activities

CRIEPI produced various research results helping to solve the issues faced by the electric power industry and society. Moreover, in order to lead reforms in the supply and usage of power and other energies, we have formulated research strategy from a mid-to-long term perspective.

Contributing to the electric power industry and society through producing/providing results

- CRIEPI injected resources with priority to R&D aimed at solving common issues faced by the electric power industry and, based on PDCA through good communication with clients, etc. promoted steady research and produced results. In concrete terms, we have developed a behavior evaluation method for masses of rock when slope failure occurs in the periphery of a nuclear power plant, wood biomass fuel capable of a high co-firing rate in coal-fired power generation and AI-based technology to determine the deterioration of transmission towers. We also developed a tool to analyze the interaction between energy resource usage on the customer side and electric power quality in smart communities.
  Furthermore, after identifying events predicted to manifest in the future, we engaged in research to offer solutions to the associated issues and new values, producing results in the various areas of the electric power business such as the building of a security verification environment for network control systems and the development of an all-solid-state battery with excellent safety. ➡ See Fig. 1, p.16 to p.59 [2-2. Major Research Results] (22 in total)
- CRIEPI responded to research requests in accordance with accidents, trouble and other issues at electric power companies by customizing our cultivated knowledge, technologies and research results to suit the circumstances of the individual worksite and swiftly offering suitable solutions for such situations. ➡ See Fig. 2
- CRIEPI proactively engaged in consigned research projects from the Japanese government, etc. and challenged ourselves by undertaking leading research addressing various issues that could improve the research and research abilities helping to solve issues faced by the electric power industry. Such research themes included advancement of the method for evaluating the impact of irradiation on nuclear reactor pressure vessels and core internals, as well as the development of CO_2 recovery-type next-generation IGCC technology.

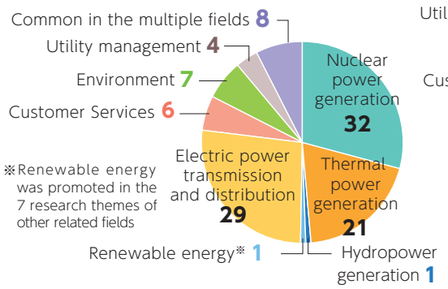


Fig. 1 No. of research themes by field for FY2017

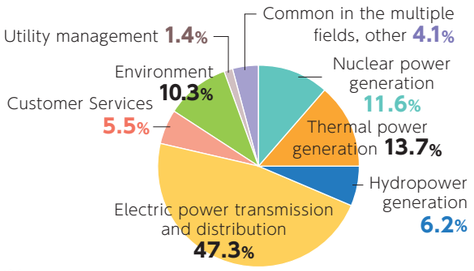


Fig. 2 Consigned research projects from electric power companies for FY2017 (percentage of cases by field)

Initiatives for formulating research strategy to lead reforms

- In order to lead reforms in the supply and utilization of electric power and other energy forms, based on the three higher perspectives listed below, CRIEPI has clarified the issues we need to tackle by unleashing our total capabilities not only in relation to each business area of the electric power industry, but also transcending conventional business frameworks, and formulated mid-to-long term research strategy. We will appropriately reflect this research strategy in our future research plans.

Overall optimization of energy production, distribution and utilization

Assuming the expansion of renewable energy, this initiative aims at the overall optimization of not only production, distribution and utilization of electric power, but also gas and thermal energy forms in order to simultaneously establish decarbonization, economic and stable supply, etc.

Digital transformation

In order to support digital transformation (social and business changes through digital technology) in the electric power industry, CRIEPI is proposing new values by utilizing not only IoT and AI, but also advanced digital technology such as cloud robotics.

Risk base technology system

Using probabilistic methods, etc. to quantitatively and hierarchically appraise the increase/decrease of the risks individual technological choices could have on energy systems to guide efficient investments overall.

Higher perspectives for energy system reforms

Strengthening and developing fundamental research ability

- As of the end of FY2017, CRIEPI employed a total of 739 people comprising of 653 research personnel and 86 administration personnel. Research personnel specialize in a broad range of fields ranging from electricity, civil engineering and construction to socioeconomics. Of the 739 total, 393 personnel have obtained their doctorates.
  ➡ See Fig. 3
- CRIEPI engaged in the professional development of researchers who possess both high-level expertise and a deep understanding of the electric power industry through the promotion of new, challenging research and element technology research, long-term dispatch to electric power companies, etc.
- CRIEPI carefully selected large research facilities essential to solving issues faced by the electric power industry, then made the necessary installations and updates. Such facilities include a thermal power supply water treatment tester used in the development of a substitute agent for hydrazine, the anticorrosive agent used in high-pressure boilers of power plants, as well as a radiation sensitivity analysis facility used to elucidate the mechanism of dose rate effects aimed at higher rationalization of radiation protection criteria. ➡ See p.13 [Major New Research Facilities]
- Continuing our relationship with institutions both in Japan and abroad possessing high technological standards, CRIEPI actively promoted researcher exchanges, information exchanges relating to R&D, etc. Particularly in regards to EDF (France), we dispatched researchers involved in customer communication networks and engaged in the development of new fundamental technologies combining our respective technologies. Meanwhile, CRIEPI accepted EDF researchers involved in seismic motion studies and strengthened our collaboration even further. We also actively promoted joint research with EPRI (U.S.A.) in the field of nuclear power generation. ➡ See p.67 [Research Networks]

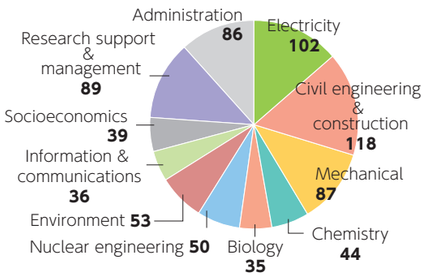


Fig. 3 Personnel configuration by subject field as of end of FY2017

Contributed to an electric power industry and society that utilizes our intellectual property and proprietary knowledge/technologies

- CRIEPI broadly disclosed its research results to the general public through research reports and academic papers so that such results could benefit the electric power industry and society at large. We also utilized our patents and software in various ways, including contributing to the enhanced safety of nuclear power generation through providing electric power companies with TONBOS, software for evaluating the speed of tornado missiles.
  ➡ See p.66 [Research Results / Intellectual Property]
- CRIEPI attended various government and academic committees to contribute to the formulation of standards and public policies relating to electric power and other energy forms such as amendment to the international standard “Guidelines for the Application of Insulation Coordination” by the IEC aimed at achieving rational insulation design of electric power grids.
- Upon request from electric power companies and manufacturers, CRIEPI performed short-circuit tests on power equipment such as circuit breakers, etc. at our High Power Testing Laboratory. We also fulfilled our responsibility as a PD Examination Center under the PD (Performance Demonstration) certification program which involves performing ultrasonic flaw detection on nuclear power generation equipment.

Proactive dissemination of research activities and results

- CRIEPI hosted research report briefings and symposiums, as well as published PR materials including CRIEPI TOPICS to present society with our research activities and results through disseminating information via various forms of media.

Steady promotion of research base development and rationalization, sophistication and cost reduction of operational tasks

- CRIEPI continued to promote research base development aimed at strengthening our research ability and reducing fixed management overheads through activities such as the practical completion of a base in Yokosuka Area by the construction of a material analysis building and transfer of the research function from Komae Area, as well as finalizing the concept for a new building that will serve as a hub of researcher activities, etc. in the Abiko Area.
- While maintaining our personnel scale at the reduced level of 750 members, in preparation for the establishment and strengthening of organizational management able to flexibly respond to changes in the management environment, CRIEPI pushed ahead with the construction of a new fundamental task system and task outsourcing. We also continued efforts for cost reductions in both research and operational aspects through the ongoing promotion of competitive quotations in our procurement activities, etc.

Looking ahead to changes in the environment surrounding the electric power industry, CRIEPI engaged in various research projects for the creation of new values relating to achieving improvement of electric power facility safety, rational maintenance and operation, as well as the supply and utilization of energy. We have produced concrete results through such efforts.

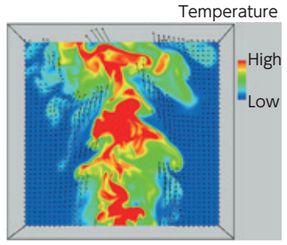
Research was promoted for the nine areas ranging from nuclear power generation to common in the multiple fields. Please refer to p.14 for a list of research subjects.
Below is an outline of the research results for each area. Also, from page 16 onwards, we have provided detailed descriptions of the major research results worthy of special mention.

Nuclear Power Generation

Advancements of the safety of light water reactors

Establishment of evaluation techniques for low-frequency phenomena

- In relation to securing safety in nuclear power facilities during earthquakes, CRIEPI elucidated the factors that stop rupturing of active faults in zones where the seismic velocity changes rapidly using on-site investigations targeting past earthquakes and seismic wave tomography analysis.
- In order to predict the impact of ash fall damage caused by large-scale eruptions, CRIEPI used simulation to recreate the development process of the eruption column, which determines ash fall characteristics (right), and elucidated the transport characteristics at the interface between the atmosphere and eruption column.
- In order to improve the safety of nuclear power plants in relation to slope failure caused by earthquakes, CRIEPI used 3D analysis to reproduce rock behavior at the time of slope failure and developed a method to evaluate the impact force due to falling rock with higher accuracy. See p.16



Eruption Column Simulation
Recreate a scene where high-temperature liquid billows upwards together with the nearby air while spreading to the surrounding area

Advancement of core damage assessment methodology

- In order to improve the reliability of safety evaluations for reactivity initiated accidents (RIA), we performed an experiment whereby we simulated thermal-hydraulic behavior during an accident and elucidated the conditions causing the temperature around the fuel inside a nuclear reactor to rise suddenly, as well as the relationship with pressure.

See p.18

Evaluation of impact of major accidents

- For the timely implementation of marine monitoring of radioactive substances according to the emergency plan complied by the government in the case of nuclear power plant accidents, we performed marine diffusion simulation of eight ocean regions related to 18 Japanese nuclear power plants. From the results have been obtained the knowledge to identify those areas to be monitored in each ocean region.

Establishment of probabilistic risk assessment (PRA) technology

- With the aim of establishing fire and flooding protection measures in nuclear power plants, we have developed fire and flooding PRA implementation procedures for the Japanese plants using U.S. evaluation guides as references, compiling Japanese guides.

Promotion and advancement of independent public safety activities

- For the sake of improving our response ability during emergency situations in nuclear power plants, we prepared a Team Resource Management (TRM) Skill Training Guide (right) that includes non-technical skills, and applied this to drills for the personnel of emergency response headquarters in power plants.

The TRM skill and training guide prepared by CRIEPI

Seismic Wave Tomography Analysis
A technique to surmise subterranean structure by measuring the time a seismic wave takes to travel from an earthquake epicenter to the observation point using a combination of various earthquake epicenters and observation points.

Rupturing
The phenomena whereby multiple faults are destroyed simultaneously during an earthquake.

Probabilistic Risk Assessment (PRA)
PRA is a systematic method to analyze various accident scenarios which could occur in engineering facilities such as nuclear power plants, as exhaustively as possible to quantify the frequencies and impacts of the scenarios. The risk values expressed in the product of the frequencies and impacts evaluated by PRA demonstrate how safe the facilities are.

Non-technical Skills
In contrast to individual technical skills such as specialist knowledge and skills, non-technical skills are those such as communication and teamwork mainly engaged in within an organization.

Yield Stress
Yield stress is the minimum stress that materials to be permanently deformed.

Thermal Aging embrittlement
A reduction of toughness over time due to microstructural evolution which is caused by exposure to high temperature environment.

Bentonite
Clay formed by the weathering of tuff, etc. Bentonite swells when it absorbs water, making it difficult for water to penetrate.

Medium Depth Disposal
This method of disposal targets the low-level radioactive waste with relatively high radioactivity and involves burying the waste deep down in the earth with ample leeway for general subterranean utilization. There is a requirement to secure a depth of 70 meters or more for at least the next 100,000 years even when ground erosion is taken into consideration.

Safe and stable operation of light water reactors

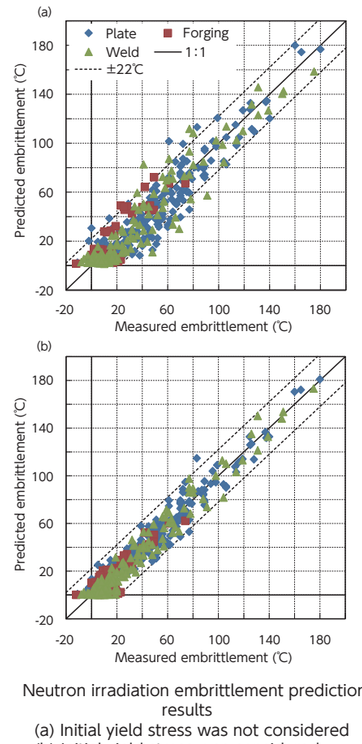
Improvement of maintenance techniques for light water reactors

- Neutron irradiation embrittlement prediction method for reactor pressure vessel (RPV) steels was modified by considering initial yield stress of the steels to explore more precise evaluation of neutron embrittlement of RPV steels (the figures on the right).
- According to Atomic Energy Society of Japan standard, CRIEPI proposed guidelines to evaluate thermal aging embrittlement of cast austenitic stainless steels in Japanese BWRs.
- CRIEPI succeeded in introducing internal cracks in mockups for dissimilar metal welds (DMW) performance demonstration. To improve crack sizing in DMWs, we developed a new measurement procedure. See p.20

Maintenance and expansion of radiation protection systems

- In order to elucidate the mechanisms of radiation carcinogenesis at low dose rate, CRIEPI clarified that damaged stem cells can be excluded from normal tissues by experiments simulating stem cells at low dose rate.

See p.22



Neutron irradiation embrittlement prediction results
(a) Initial yield stress was not considered
(b) Initial yield stress was considered

Establishment of nuclear fuel cycle technology

- With the aim of establishing a monitoring technique in preparation for the introduction of the concrete casks used for storing spent fuel in Japan, we developed a method based on temperature change to detect leaks of helium from the canister due to stress corrosion cracking. See p.24
- In order to support safe operation of spent fuel reprocessing plants, we clarified the formation mechanism of water-soluble crystalline material called as “yellow phase (YP)” and needle-like crystals containing platinum group elements, which are the major causes of problems during vitrification of highly-radioactive liquid waste.

See p.26

Support for radioactive waste disposal operations

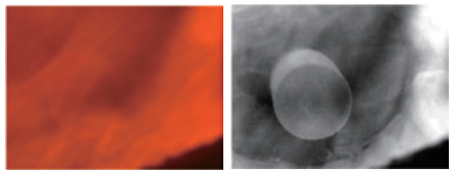
- In order to appropriately evaluate the safety of radioactive waste disposal into the future, CRIEPI developed an analysis code able to handle the complicated phenomena consisting of thermal, hydraulic and mechanical processes in the near field of disposal facilities and improved reliability by conducting comparisons of analysis results with five other participating institutions in joint international research program.
- In order to support safe operation of spent fuel reprocessing plants, we clarified the formation mechanism of water-soluble crystalline material called as “yellow phase (YP)” and needle-like crystals containing platinum group elements, which are the major causes of problems during vitrification of highly-radioactive liquid waste.
- In order to support applications for medium-depth disposal of radioactive waste complying with new regulatory requirements, CRIEPI conducted a dose assessment sensitivity analysis targeting medium-depth disposal facilities and newly presented a method displaying safety indicators based on probability theory by individual items relating to facility design and installation.

2–1. Outline of Results

Thermal Power Generation

Ensuring reliability of existing thermal power plants

- In order to reduce maintenance costs of water wall tubes used in thermal power plant boilers, CRIEPI proposed a method to determine the optimal timing to perform chemical cleaning of the scale adhered on the inner surface of tubes to maximize tube life and clarified that it was possible to reduce the cleaning frequency. ➡ See p.28
- In order to help countermeasure ash adhesion obstruction in pulverized coal fired thermal power plants, we applied optical filter and image processing to develop a technology that clearly observes furnace structures in pulverized coal combustion field (right).
- As a measure to prevent the corrosion of plant boilers used in coal fired thermal production, CRIEPI improved “CRIEPI Coat”, a coating technology to prevent sulfide corrosion developed by CRIEPI, and succeeded in further reducing sulfide corrosion and groove corrosion.
- CRIEPI conducted the chemical analyses and creep tests for welded joints of high chromium steel pipes, which exhibit excellent material strength at high temperatures, in order to improve the diagnosis accuracy of creep damage for safety operation of thermal power plants. As a result, we clarified that the variation of creep strength is dominated by the composition ratio of the base metal of the material.
- In order to help establish countermeasures for biofouling in the cooling water systems of thermal power plants, CRIEPI developed a technique to evaluate the effects of chemical treatment based on indoor experiments and on-site water system simulator experiments.
- With the aim of expanding the effective utilization of coal ash, in order to speed up the leaching test process at carry-out, we collected the arsenic, selenium, etc. present in eluent by using chelating agent and established a technique for the quantitative analysis using X-Ray Fluorescent in a short period of time.



Original image　　Processed image

Clear visualization of furnace structures using an optical filter and image processing

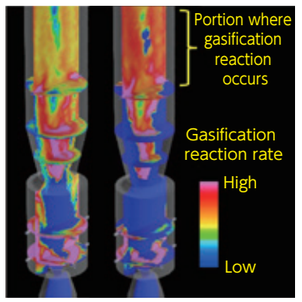
Pulverized Coal Fired Thermal Power Generation
A method of generating power by pulverizing coal into a powder form, combusting this in a boiler and driving turbines using the generated steam.

Creep Damage
A phenomenon whereby stress works constantly on metal causing the distortion to increase over an extended period of time and ultimately break.

Chelating Agent
A chemical substance that bonds with metal ions and increases solubility.

Thermal technology to mitigate environmental load

- In order to further improve the thermal efficiency of coal gasification combined cycle system, which helps to mitigate environmental load, CRIEPI performed an experiment using a bench-scale gasifier and a numerical analysis technique (right) and verified that gasification efficiency could be improved by adding steam into the gasifier.
- In order to reduce CO_2 emissions in coal fired thermal power generation, CRIEPI developed carbonized woody biomass fuel capable of high co-firing rate without the need for major modifications to conventional power plant equipment. ➡ See p.30



Comparison of gasification reaction rates when steam is not added (left) and when it is added (right)

Diversification of fossil fuels

- With the aim of reducing fuel cost due to fuel type expansion in thermal power generation, CRIEPI evaluated the combustion characteristics when high-fuel ratio bituminous coal (fuel ratio 2.5 – 4), which has not been used to date, is blended with the current bituminous coal and clarified that both NOx conversion ratio and uncombustion fraction have correlation with the fuel ratio of the blended coal.
- In order to contribute to stable operation of pulverized coal fired thermal power plants with utilization of low-grade fuel, that is used to reduce power generation costs, CRIEPI developed a numerical analysis model to evaluate the combustion condition inside a pulverized coal fired boiler, and clarified the generation and decomposition behavior of NOx, that is relevant for air pollution, inside boilers.

Fuel Ratio
The combustible components of coal are divided into volatile matter and fixed carbon. Volatile matter volatizes from a coal upon heating and have high combustibility. Fixed carbon doesn’t volatize and have poor combustibility. Fuel ratio is the ratio of fixed carbon to volatile matter and if the fuel ratio is high (the amount of volatile matter is minimal), ignitability and combustibility are poor.

Gas Turbine Combined Cycle (GTCC)
A power generation method combining gas turbine and steam turbine.

Column
A cylindrical-shaped container or equipment used in experiments.

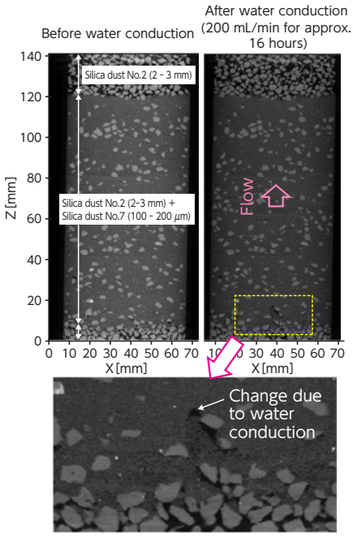
Response to large-scale introduction of renewable energy

- In order to respond to load fluctuation accompanying the increase of renewable energy connected to the conventional power grid, aiming to further improve the operation performance of gas turbine combined cycle (GTCC) which has superior start-up speed and load following ability, CRIEPI built a dynamic characteristics analysis model able to calculate the power generation output and temperature/pressure of complex GTCC plants for utilization in preliminary studies when making an operational change.

Hydropower Generation

Disaster prevention and maintenance and management for hydropower facilities

- In order to assess the risk of public damage arising due to the damage or destruction of hydropower facilities such as intake chambers in the event of natural disasters, CRIEPI developed a program to analyze water and debris penetration requiring only simple settings. ➡ See p.32
- In order to elucidate the mechanism of the phenomena whereby slopes become unstable due to an increase in subterranean water after heavy rain, we ran water resembling subterranean water through a column filled with sand and succeeded in visually capturing the internal state of change in the sand structure due to water conduction by using a micro-focus X ray CT (right).
- With the aim of establishing a method to evaluate the values of hydropower plants from multiple aspects (hydropower premium), CRIEPI investigated various forerunner utilization value assessments and extracted case studies of assessments indicating added value relevant to river environments and ecosystems.



Results of photographing column using micro-focus X ray CT

Renewable Energy

System resilience with high integration of renewable energy sources

- To contribute to power system stabilization in the case of increased renewable energy penetration, in addition to the existing single-phase power source model targeting household solar power generation, CRIEPI developed a 3-phase power source model enabling the analysis of an unbalanced fault assuming mega solar and a load supply system aggregation model including a synchronous machine with renewable energy, which is useful for large-scale power system analysis.

Unbalanced Fault
A Fault in which one or two of three-phase AC transmission lines (one set with three) become temporarily unable to transmit power by lightning, etc.

Expanded introduction of biomass and geothermal power generation

- To contribute to further popularization of geothermal power generation, CRIEPI conducted the feasibility study of geothermal power generation systems with even greater efficiency and economic performance and indicated that a profitable system could be built by using the biomass material obtained in forest thinning as an external heat source. Moreover, we identified thirteen prospective locations for the system based on aresult of maps overlay analysis using geothermal resource potential and biomass procurement potential in Japan. ➡ See p.34

2-1. Outline of Results

Electric Power Transmission and Distribution

Response to reforms in electric power system

- In light of the fact that power system operation and planning shall manage increasing uncertainty due to plans for the 2020 legal separation of electrical power generation and transmission and the expanding introduction of renewable energy, CRIEPI improved the functions of its proprietary "CPAT" software for electrical power grid analysis and saw potential for the swift response to various issues of renewable energy sources, system stabilization device introduction, etc.
- In order to leverage the balancing market to be established by 2021 in line with the electricity system reform and achieve low-cost, stable operation and control of power systems, CRIEPI developed accurate demand and supply plan simulation model and automatic generation control simulation model, and clarified the technical challenges and cost reduction benefits associated with the establishment of a balancing market. ➡ See p.36
- For power system simulations including HVDC (High-Voltage Direct Current) links used for strengthening wide-are interconnections and also for simulations related to integration of renewable-energy generation systems, we have achieved faster simulation speed for eXpandable Transient Analysis Program (XTAP).
- In order to support the streamlining of operational tasks through linking the various systems of general power transmission and distribution businesses, we have proposed to use the Common Information Model (CIM), an international standard relating to system linkage, for that. CRIEPI investigated the current status of its standardization, as well as examples of application overseas, thus compiling useful information concerning CIM's application in Japan.

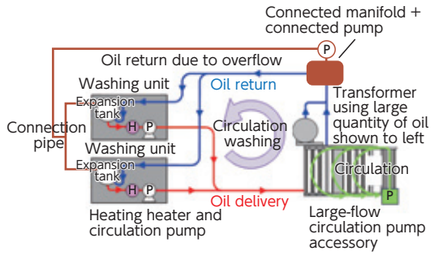
Formation, maintenance and upgrades of substations and transmission lines

Advancing preservation technology for aged facilities

- In order to reduce labor required to judge the necessity of applying anti-corrosive agent to transmission towers, CRIEPI developed a technique to determine the extent of corrosion from aerial photographs. ➡ See p.38
- In order to safely and swiftly measure the density of salt adhered to the surface of insulators used in the insulation of transmission towers and power cables from the ground, CRIEPI developed a technology to quantify sodium and chlorine using laser-induced breakdown spectroscopy. ➡ See p.40
- With the aim of exploring the possibility of utilizing an insulating gas to substitute sulfur hexafluoride as part of a renewal plan for aging equipment, CRIEPI conducted experiments to evaluate the safety and basic insulating performance of an alternate gas currently being researched in Europe and identified the issues concerning operational and safety aspects.

Support to streamline facility design and operate facilities

- In order to easily determine the damaged point when transmission lines are struck by lightning, CRIEPI verified the position location method and the electric charge estimation method in the new lightning location system proposed by ourselves and saw potential to improve measurement accuracy.
- In order to clarify the impact of the electromagnetic field created by transmission lines and electrical power facilities on drones in mid-flight for maintenance and inspection of overhead transmission lines, CRIEPI developed experiment techniques to evaluate resistance against the three types of fields, namely a commercial frequency electrical field, a commercial frequency magnetic field and an electromagnetic field radiated from spark discharge. ➡ See p.42
- In the heated forced circulation washing method to remove PCB from the contaminated transformers with trace amount of PCB, there was an issue with insufficient oil circulation when washing large transformers. To solve this, CRIEPI designed an oil circulation system connecting two washing units which made it possible to wash large transformers by maintaining a sufficient amount of circulated oil (right).



Heated washing of transformers using large quantities of oil with an oil circulation system connecting two washing units

CPAT
An integrated software package developed by CRIEPI for electrical power grid analysis. CPAT is compiled from the three flagship programs of power flow analysis, transient stability analysis and steady-state stability analysis and is capable of highly-accurate analytical calculation with appropriate consideration to the various properties of electrical power systems.

XTAP
A program for simulating transients of electrical circuits and their control systems with its primary application to power systems. It has been and is currently developed by CRIEPI. XTAP shows advanced simulation performance over existing similar programs especially for simulations including power-electronics converters such as grid-connection inverters of photovoltaic power generation systems.

Sulfur Hexafluoride (SF_6)
An insulation gas used widely for the insulation of electrical devices such as gasblast circuit breakers and gas insulated switchgears. SF_6 has been identified as being an extremely potent greenhouse gas.

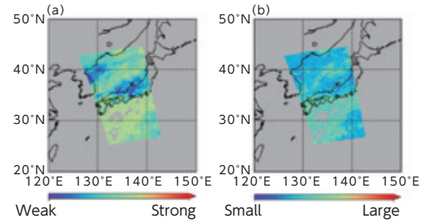
Lightning Location System (LLS)
A system with multiple sensors to detect the electromagnetic field waveforms generated from lightning strikes then estimate lightning location, time, peak current amplitudes, etc. based on data analysis.

PCB
The abbreviation of polychlorinated biphenyl. This material was once widely used in electrical devices due to its excellent insulation performance, but has been prohibited from manufacture or use due to its toxic nature. An Act on Special Measures stipulates that all PCB-affected devices must be treated by March 31, 2027.

Response to changes in supply form and demand-side changes

System resilience with high integration of renewable energy sources

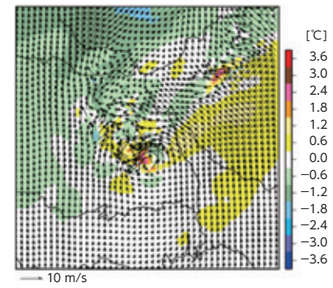
- In order to predict the impact on electrical power systems of large variation in output of photovoltaic power generation, CRIEPI developed a technique to estimate the intensity and variation characteristics (standard deviation) of ground surface radiation over several hours using observed data from weather satellites, as ground surface radiation affects the variation in a photovoltaic power generation system's output (right).



Estimated intensity (a) and standard deviation (b) of ground surface solar radiation

Response to disaster and human risks

- In order to elucidate the cable surf-riding phenomenon that causes damage to underground power cables due to vehicles passing overhead, CRIEPI developed a model test apparatus of one-tenth of actual size and developed an evaluation model taking account of most of factors of the surf-riding phenomenon. ➡ See p.44
- In order to improve the accuracy of predicting extreme weather, CRIEPI developed a data assimilation system to incorporate weather radar information in model calculation. This has made it possible to make highly accurate predictions of unexpected weather phenomenon such as tornados up to several hours in advance (right).
- In order to improve the prediction accuracy of the damage to power distribution equipment due to typhoons, CRIEPI introduced the daily sea-level pressure prediction results obtained by the weather forecasting and analysis system NuWFAS into the typhoon damage estimation system RAMP-T. Thus, we made it possible to predict typhoon damage by adding wind velocity information predicted with high precision.
- With the aim of verifying the efficacy of security measures against cyber-attacks on power equipment monitoring and control systems, CRIEPI built a cyber-security verification environment simulating a network control system and a substation monitoring and control system. ➡ See p.46



Distribution of airflow (vectors) and temperature deviation (color) inside and outside tornado-producing cumulonimbus

Heat Exchanger
A device used to transfer heat from hot substances to cold substances.

Customer Services

Promotion of energy conservation and electrification and enhanced customer satisfaction

- CRIEPI devised a new heat pump-type AC system for electric vehicles utilizing the Desiccant-Coated Heat Exchanger (DCHE). By using the dehumidifying ability of the desiccant to prevent condensation from forming on car windows as well as efficiently utilizing the heat generated during dehumidification, less battery power is required for heating, thus ultimately improving the vehicle's travel distance.
- In order to contribute to high-level temperature/humidity control in large-scale greenhouses utilizing heat pumps highly effective at reducing CO_2 emissions, CRIEPI developed a wireless IoT temperature/humidity sensor that operates using a solar cell and makes it possible to measure multiple points cost-efficiently.
- CRIEPI developed a novel AI technique that predicts surplus of contract-based electrical power, with the aim of providing an e-mail alert service for user cost reduction. ➡ See p.48

2-1. Outline of Results

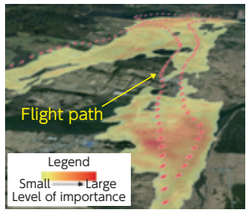
Environment

Response to environmental policy and regulations

- In order to appropriately reflect the latest trends regarding global warming countermeasures in the electric power business, CRIEPI performed analyses pertaining to carbon pricing and clarified many issues exist in both the explicit pricing of carbon tax, emissions trading, etc. and implicit pricing in line with energy-saving related regulations.
- Toward the goal of establishing measures to reduce CO_2 emissions with scientific and economic rationality, CRIEPI analyzed the economic performance and local receptivity of the CO_2 capture and storage technologies proposed as global warming countermeasures and clarified risk factors in the case that these were introduced in Japan.
- In order to assess the health risks of the intermediate-frequency magnetic fields used in IH cookers, CRIEPI performed an exposure experiment using laboratory animals under a magnetic field largely exceeding the intensity stipulated in international exposure guidelines and clarified there was no increase in the incidence of cancer within the scope of the magnetic field and genetically modified mice model used for the experiment. See p.50

Efficient environmental assessment

- With the aim of realizing efficient environmental assessments to be performed when newly constructing or replacing power plants, CRIEPI developed a general purpose 3D numerical simulation model applicable to the prediction of warm water discharge and cold water discharge as well as the recirculation evaluation of intake water. See p.52
- In order to evaluate the impact of the location of wind power facilities on important bird species, CRIEPI established a technique to analyze areas and their importance of the target birds use as feeding and resting grounds based on flight route data (right).



Map showing impact on whooper swan behavior
The areas colored in red show the impact of a power plant location on whooper swan behavior, with the degree of impact being greater the darker the shade of red.

Utility Management

Ensuring consistency of power system reforms and energy measures

- With the aim of identifying issues with the introduction of "Connect & Manage," a newly emerged utilization scheme of power transmission networks, CRIEPI investigated cases of forerunners in overseas locations and clarified the risk of system constraint deviations such as voltage deviation caused by increase of connected power units as well as excess power flow beyond transmission capacity.
- In regards to the risks that recovery of power source fixed costs may no longer be achievable after electricity system reform, CRIEPI performed an evaluation based on a simulation of future wholesale electricity prices together with a survey of overseas trends, and clarified the need for appropriate design of the capacity market scheme to be established.
- CRIEPI applied its model system to analyze the economic impact if the nuclear power ratio in 2030 was less than the target indicated in the Long-term Energy Supply and Demand Outlook published by Japan's Ministry of Economy, Trade and Industry. See p.54
- In order to elucidate the factors causing shifts of household/commercial energy demand, CRIEPI performed analyses of the demand for electrical power and gas by uses as well as by industrial sectors, and clarified the effects of factors such as income, production, price, no. of household members, temperature, etc. on past demand trajectories.

Connect & Manage
A scheme allowing the connection of power generation facilities with certain conditions in response to requests from power utilities seeking system connection. The rules of transmission line utilization are prioritizing connection to the power transmission network (Connect) then minimizing output in the case of oversupply (Manage).

Capacity Market
A market that does not trade supply volume (kilowatts hour: kWh), but rather future supply capability (kilowatts: kW). "Capacity market" is a scheme whereby system operators allocate a monetary value to the capacity of a power plant, etc. and trade this on the market in order to efficiently secure supply capability for several years into the future.

Common in the Multiple Fields

Overall optimization through supply/demand coordination

- With the aim of realizing smart communities, CRIEPI developed a mutual effect analysis tool for communities and power distribution systems to achieve both rationalized operation and facility construction for power transmission/distribution systems as well as economic community operation. See p.56

Common technology for application in diverse fields

Electric double layer electret
A material with a quasi-permanent electric charge deviation (electric double layer) that is created by sandwiching an electrolyte between electrodes then applying an electric voltage.

- As part of efforts to establish rational maintenance and operation technology for electric power equipment, CRIEPI engaged in activities for the advancement of energy harvesters (environment energy harvesters), which is necessary for maintenance-free status monitoring and utilized our original material, electric double layer electrets, to successfully fabricate a vibrational energy harvester capable of generating a voltage of 2 V or more from low frequency vibrations 10 Hz or less, which had previously been difficult to accomplish with the conventional method.
- Long-life rechargeable batteries are essential for system stabilization with increase in renewable energy introduction and popularization of electric vehicles. CRIEPI developed a technique to predict remaining lives of the batteries, based on the characterization of the positive and negative electrodes of the batteries. Development of all-solid-state batteries, which consist of flame-retardant materials and are advantageous for risk reduction of fire accidents, is also in progress. See p.58

Major New Research Facilities

Thermal power water supply treatment tester

This equipment is used to elucidate the corrosion behavior of steam-water circuits in thermal power plants. The equipment has an injecting system of chemicals such as ammonia and hydrazine* under supercritical (395℃, 28 MPa) and subcritical (360℃, 22 MPa) conditions. The target of our investigation is, for example, corrosion and fouling of water wall tubes. Hydrazine has been identified as a carcinogenic substance. As a result, its use will be regulated in Europe by 2020. Also in Japan, hydrazine will be likely subjected to regulation in near future. The equipment is used for development of an appropriate substitute of hydrazine.

*Hydrazine: A weak basic substance expressed with the chemical formula of N_2H_4 which has been used up to date as a common oxygen scavenger in the high-pressure boilers of thermal/nuclear power plants.

Radiation sensitivity analysis facility

Amidst a worldwide trend of increasingly-stringent radiation protection standards, the establishment of radiation protection standards with scientific rationality based on leading biological research results is imperative. CRIEPI uses this facility to elucidate the mechanism of dose rate effects on basic carcinogenic influence.
In addition to utilizing an X-ray microbeam irradiation device which irradiates cells with X-ray beams, by using a next-generation DNA sequencer, the core component of this facility, it is possible to perform rapid analysis of genetic information for the irradiated cells. Based on this, CRIEPI is proceeding with a practical demonstration of the potential for stem cells to accumulate mutations and reflecting this in radiation protection standards. See p.22

List of Research Subjects

Nuclear power generation

●Advancements of the safety of light water reactors

■ Enhancement of systems and structures to secure safety

・Promotion of Risk Informed Decision Making Process at Nuclear Power Plants

■ Establishment of evaluation techniques for low-frequency phenomena

・Development of Evaluation Method of Fault Activity for Nuclear Facilities
・Development of Evaluation Method of Earthquake Motions for Nuclear Facilities
・Assessment for the risk and hazard of volcanic eruption on Nuclear Facilities
・Development of Extreme Weather Assessment and Countermeasure Technologies for Nuclear Power Plants
・Development of Tsunami Risk and Impact Assessment Technologies for Nuclear Facilities
・Development of advanced seismic safety assessment technologies for buildings, equipment and pipes of nuclear power plants
・Development of advanced seismic safety assessment technologies for grounds and structures of nuclear power plants

■ Advancement of core damage assessment methodology

・Development of safety evaluation techniques prior to core damage
・Technology Development for Performance Evaluation of Nuclear Fuel and Reactor Core during Severe Accidents
・Research on Evaluation Technology of Accident Progression and Related Phenomena after Core Damage

■ Evaluation of impact of major accidents

・Development of evaluation method of radioactive material in environment

■ Establishment of probabilistic risk assessment (PRA) technology

・Development of risk assessment methodology for nuclear facilities
・Development of internal fire and flooding prevent methodology introducing risk informed evaluation in nuclear facilities

■ Promotion and advancement of independent public safety activities

・Development of voluntary safety action programs for nuclear power stations in consideration of human factors

●Safe and stable operation of light water reactors

■ Improvement of maintenance techniques for light water reactors

・Development of evaluation techniques for pipe thinning at light water reactors
・Improvement of preventive maintenance technology for LWR components and piping
・Improvement of water chemistry for dose rate reduction
・Improvement of integrity evaluation method for reactor pressure vessels
・Improvement of integrity evaluation method for core internals, piping and other components
・Development of nondestructive inspection techniques for components and piping in nuclear power plants

■ Maintenance and expansion of radiation protection systems

・Quantitative evaluation of low-dose radiation risk and reflection to radiation protection systems

■ Greater advancements in light water reactor technology

・Technology improvement for performance evaluation of nuclear fuel and reactor core

●Establishment of nuclear fuel cycle technology

・Development of long-term storage management technologies for spent fuel
・Development of technology to improve safety and stable operations of nuclear fuel reprocessing plants
・Safety assessment for overseas return waste storage
・Securement of options for future nuclear fuel cycle

●Support for radioactive waste disposal operations

・Enhancement of reliability of long-term safety assessment technologies for radioactive waste disposal
・Development of streamlined approach for the implementation of radioactive waste disposal project

●Ongoing long-term use of nuclear reactors

・Technology development for metal fuel fast reactors and pyroprocess

●Decommissioning nuclear reactor facilities

・Fundamental technology development for decommissioning and dismantling of nuclear facility
・Development of decommissioning, defueling and remediation technologies for severe damaged nuclear site

Thermal power generation

●Ensuring reliability of existing thermal power plants

・Development of condition diagnostic and maintenance management technologies of thermal power plants
・Development of on-site diagnostic technique for boiler tube failure in thermal power plant
・Improvement of remaining life assessment, diagnosis and maintenance for boiler and steam turbine components in thermal power plant
・Development of preventing technology for corrosion and corrosion fatigue on feed water and steam system components in thermal power plant
・Development of the hard clinker countermeasure in pulverized coal fired boilers
・Development of preventing technology for sulfide corrosion on boiler tube in thermal power plant
・Development of life assessment technology for high temperature structural components made of high chromium steels in thermal power plants
・Development of maintenance and management technologies for gas turbines
・Development of countermeasures for biofouling and jellyfish invasion at cooling water intake structure of coastal power plant
・Development of performance degradation assessment and enhancement methods for thermal power civil engineering and building RC structures
・Development of technologies for increasing use of coal ash

●Thermal technology to mitigate environmental load

・Development of maintenance and improvement technology of environmental facilities for thermal power plants
・Investigation and Evaluation of the influence on trend of the environmental regulation for thermal power station
・Study on technologies to evaluate the structural integrity of components in next-generation fossil-fuel power generation
・Development of technologies to improve operation of IGCC plant and reduce environmental loading
・Feasibility study of triple combined cycle system based on pressure performance of SOFC bench-scale cell
・Development of technologies for expanded use of biomass in thermal power generation

●Diversification of fossil fuels

・Diversification Technologies of Fuel Types for Thermal Power Generation

●Response to large-scale introduction of renewable energy

・Development of technology to improve load following capability of thermal power systems
・Improvement of flexible operations of coal pulverized thermal power plant and estimation of the value of its flexibility

●Response to risk of disasters

・Natural disaster assessment and measures for thermal power plants

Hydropower generation

●Disaster prevention and maintenance and management for hydropower facilities

・Development of disaster prevention and maintenance technologies for hydropower facilities

Renewable energy

●System resilience with high integration of renewable energy sources

▽Development of next generation power distribution network system
▽Development of power system technology contributing to transmission system resilience with high integration of renewable energy sources
▽Development of supply-demand operation and control technology using energy storage system
▽Development of accurate power output estimation and forecast techniques of photovoltaic and wind power generation
▽Performance evaluation of stationary energy storage battery systems for stabilizing power grid connected with renewable energy generation
▽Analysis and evaluation for policy design to the issues arising with large scale introduction of renewable energy

●Expanded introduction of biomass and geothermal power generation

・Development of innovative technologies for promoting the introduction of geothermal power
▽Development of technologies for expanded use of biomass in thermal power generation

Electric power transmission and distribution

●Response to reforms in electric power system

・Greater advances in systems to analyze surveys and forecast economic and electric power markets to project demand
・Development of support technology for widening system operation and reinforcing system interconnection
・Development of techniques to maintain supply reliability of power system under Japanese Electricity System Reform
・Development of technologies related to electromagnetic transient simulations of power systems
・Development of technologies to construct power utilities' communication infrastructure utilizing general-purpose communications technology

●Formation, maintenance and upgrades of substations and transmission lines

■ Advancing preservation technology for aged facilities

・Diagnostic technology for overhead transmission facilities
・Diagnostic technology for underground transmission cable system
・Diagnostic technology for substation equipment

■ Support to streamline facility design and operate facilities

・A study on rationalization of insulation design of the power apparatus and systems based on the lightning risk management
・Solutions for electromagnetic compatibility and electromagnetic interference (EMC/EMI) caused by HV substations and transmission lines
・Development and estimation of countermeasure technology for fault currents to secure public safety
・Verification of washing mechanism and development of practical washing technologies for PCB removal from PCB contaminated transformer
・Development of countermeasures against wildlife causing trouble in electric transmission facilities
・Development of maintenance and replacement technologies of communication systems used for power system monitoring, protection and control

■ Next-generation equipment technology anticipating future facility upgrades

・Evaluation techniques for power semiconductors
・Development of high efficient electric power distribution facilities for next generation

●Response to changes in supply form and demand-side changes

■ System resilience with high integration of renewable energy sources

・Development of next generation power distribution network system
・Development of power system technology contributing to transmission system resilience with high integration of renewable energy sources
・Development of supply-demand operation and control technology using energy storage system
・Development of accurate power output estimation and forecast techniques of photovoltaic and wind power generation
・Performance evaluation of stationary energy storage battery systems for stabilizing power grid connected with renewable energy generation

■ Next-generation power distribution system technology compatible with greater activity in demand region

・Power quality preservation and enhancement for distribution systems with advanced customer devices

●Forming, maintaining and update power distribution facilities

・Development of evaluation technology on lightning risk management and fault current countermeasures for distribution systems
・Diagnostic technology for power distribution equipment

●Response to disaster and human risks

・Evaluation of and countermeasures against earthquake damage to distribution facilities
・Development of extreme weather forecasting and hazard evaluation methods for distribution facilities
・Evaluation of and countermeasures against damages meteorologically caused to distribution facilities
・Application of disaster mitigation and restoration support technologies for electric power distribution equipments
・Development of cyber attack corresponding technology for power equipment monitoring and control system

● : Major categories grouping research subjects related to each field
■ : Sub-categories grouping research subjects related to major categories
• : Names of research subjects
▽ : Research subjects promoted in research issues in other fields (listed multiple times)

Customer services

●Promotion of energy conservation and electrification and enhanced customer satisfaction

・Development and evaluation of advanced heat pumps
・Development of energy-saving and electrification technology in consumer and industrial sectors
・Research and development for electrification promotion of the transportation sector
・Development of Customer Satisfaction Measures utilizing Energy Related Information
・Assessment of the value of next-generation electricity demand management
・Power Retail Business Strategies and Issues in the Post FIT Era

Environment

●Response to environmental policy and regulations

・Research on domestic and international climate change policies
・Scientifically and economically rational scenarios to reduce CO_2 emissions
・Health Risk Analysis of Electromagnetic Fields and Other Environmental Factors
・Analysis of environmental expenditures and source apportionment of pollutants associated with air quality regulations

●Efficient environmental assessment

・Development of advanced and efficient impact assessment methods for atmospheric environment
・Development of advanced and efficient impact assessment methods for coastal environment
・Improved efficiency of assessment of impact on plants, animals and ecosystems and development of new evaluation methods

Utility management

●Ensuring consistency of power system reforms and energy measures

・Issues in institutional design of the electricity system reform
・Analysis for economic impact and political, regulatory and legal risk of nuclear power in Japan
・Analysis and evaluation for policy design to the issues arising with large scale introduction of renewable energy
・Structural analysis of energy and electricity demand

Common in the multiple fields

●Overall optimization through supply/demand coordination

・Optimization of advanced power supply and demand management

●Trend of develop technology in an overall electric power industry

・Analysis of global trends of technology development under changing business environment in electric power industry

●Common technology for application in diverse fields

・Development of advanced sensing technology for power plant components
・Development of high precision and high reliability analysis evaluation technique
・Trend survey of technology utilizing hydrogen
・R&D of Next Generation Electric Energy Storage Technologies
・Development of IoT solutions for Value Added Energy
・Development of elemental techniques for material strength evaluation methods utilizing miniature specimens

Nuclear Power Generation

Development of an Evaluation Technique for Slope Failure in the Periphery of Nuclear Power Plants with Application to Actual Site

Clarified the characteristics of slope failure and helped to improve safety of nuclear power facilities

Background

With the aim of improving the safety of nuclear power plants, in addition to an evaluation of slope failure in the periphery of nuclear power plants as a phenomena associated with earthquakes, there is also a requirement to evaluate the effects in the case that slope failure does occur. There is a need to conduct sufficient studies aimed at preventing the safety functions of important facilities from being affected in the event that peripheral slope failure does occur. When evaluating the effects of slope failure, one key item is the evaluation of collapsed rock behavior and CRIEPI has developed a technique for such evaluation utilizing the distinct element method (hereinafter "DEM"), etc.

Distinct Element Method

A technique for analyzing discontinuous materials. DEM expresses the analysis subject as a mass of distinct elements such as spherical bodies with free movement and sequentially analyzes the motion of each element by modeling the inter-element bonding, repellence, friction, etc.

Outline of Results

◇ Development of a technique utilizing 3-dimensional DEM analysis to evaluate the behavior of masses of rock which have undergone slope failure

Using DEM, CRIEPI developed a technique which makes it possible to identify the reach of masses of rock in the event of slope failure. As a result of applying this technique to an actual case of slope failure, we verified that the reach of the masses of rock, etc. could be recreated.

◇ Development of a modeling technique based on the impact force characteristics upon rock mass collision and DEM

In regards to the impact force when a mass of rock collides with facilities, etc., CRIEPI demonstrated it was possible to make a more realistic evaluation by considering the collision process whereby the mass of rock breaks up to gradually decrease in size and become small masses of rock by the time of collision (Fig. 1). Moreover, in addition to elucidating rock mass collisional fracture characteristics through an experiment, we performed a DEM analysis reflecting the results of the collisional fracture experiment and saw the potential for appropriately evaluating the energy required for rock mass failure (Fig. 2).

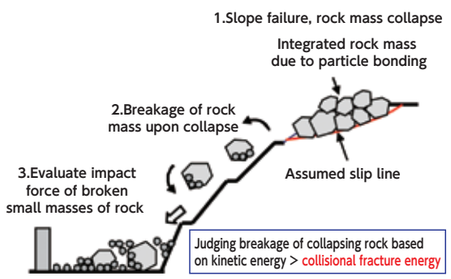


Fig. 1 Collapse and collision processes for masses of rock

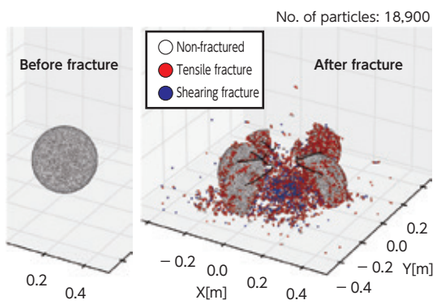
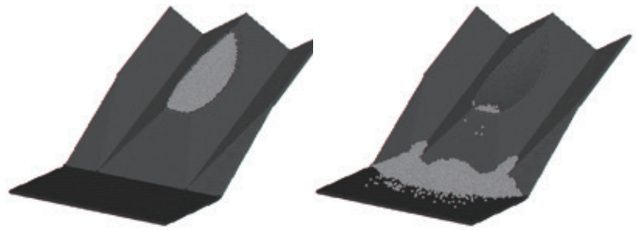


Fig. 2 Example of analyzing collisional fracturing of masses of rock using DEM

Hitoshi Tochigi
External Natural Event Research Team, Nuclear Risk Research Center

Engaging in activities for the establishment of a technique to evaluate the effects of slope failure in order to improve the safety of nuclear power plants.



Example of slope failure simulation using DEM

Application Examples of Research Results

The evaluation technique developed by CRIEPI is being adopted to assess the impact of slope failures on the emergency access routes and equipment area for implementing measures during major accidents, etc. of nuclear power plants. Moreover, it is anticipated that, moving forward, the developed technique will help achieve higher accuracy in safety evaluations of nuclear power facilities by being used for slope failure probability calculation and evaluation of effects on major facilities.

References: Nakase et al., Journal of Japan Society of Civil Engineers A1 (Structural Engineering & Earthquake Engineering) Vol. 71, p. 476 (2015)

Nuclear Power Generation

Improved Reliability of Safety Evaluations for Reactivity Initiated Accidents (RIA)

Helping to improve the safety of nuclear power plants through a thermal-hydraulic test simulating the inside of a nuclear reactor

Background

In order to evaluate the safety margin when a reactivity initiated accident (RIA) occurs in a boiling water reactor (BWR), there is a need to apply experimental data on thermal-hydraulic behavior during RIAs associated with rapid boiling inside a fuel rod bundle to the licensing analysis code. In order to experimentally simulate a RIA, which has been difficult to recreate so far, CRIEPI has developed a rapid heating technology for simulated fuel rod bundles and an original technology capable of calculating cladding tube surface temperature and boiling/condensing foam volume under high temperatures and high pressure conditions at a high time/spatial resolution, and is continuously engaging in research aimed at solving the aforementioned issues.

Outline of Results

◇ Appraisal of the pressure dependence of transient limit heat flux

In order to recreate the rapid heat generation that occurs during an RIA and precisely measure the following temperature changes, CRIEPI designed and fabricated a thermal-hydraulic simulator that heats simulated fuel with direct conduction up to 20,000 A and includes a simulated fuel rod bundle with a thermometer embedded in the cladding tube surface. Using this equipment we simulated a state whereby thermal output was rapidly increased instantaneously and expanded the correlation data of thermal output and temperature to cover the wide pressure scope from atmospheric pressure to the BWR pressure rating (7.2 MPa) (Fig. 1). From this data we obtained new insight relating to pressure dependence, i.e. the heat flux condition (transient limit heat flux) whereby the cladding tube temperature rises suddenly due to water around the rapidly-boiling simulated fuel and the surface of the cladding tube drying (Fig. 2).

◇ Quantification of foaming behavior at rapid boiling/condensing using CRIEPI's original measurement technology

Using CRIEPI's original void fraction (gas phase volume ratio) measurement technology, we assessed the complex behavior of the steam-water two-phase flow that boils and condenses within a simulated fuel rod bundle due to a sudden increase in thermal output and quantified the foaming behavior accompanying sudden change in thermal-hydraulic conditions, which is necessary to confirm the adequacy of the licensing analysis code applied to RIA.

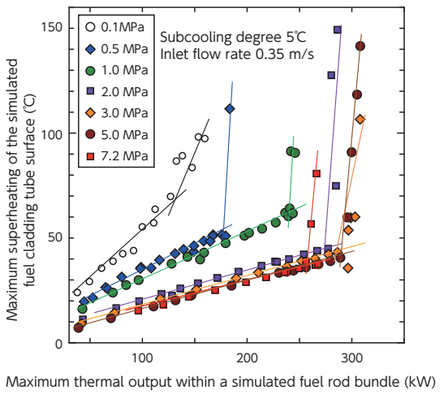


Fig. 1 Correlation between the maximum thermal output within a simulated fuel rod bundle and superheating of the simulated fuel cladding tube surface

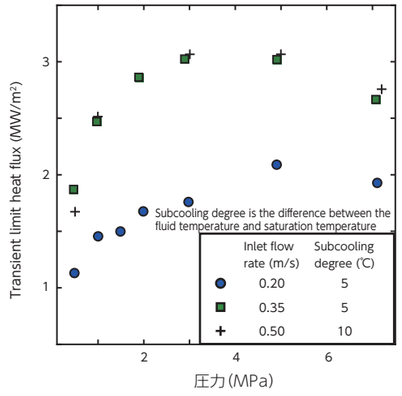


Fig. 2 Pressure dependence of transient limit heat flux

CRIEPI defined "transient limit heat flux" as the heat flux at the point where the superheating (temperature difference in relation to the saturation temperature at the set pressure) of a simulated fuel cladding tube surface suddenly increases when a predetermined pressure condition and subcooling degree (difference between the saturation temperature and water temperature at the set pressure) are established and maximum thermal output is gradually increased. When CRIEPI investigated this transient limit heat flux in relation to pressure conditions, we observed its tendency to reach its maximum value in the vicinity of 5 MPa.

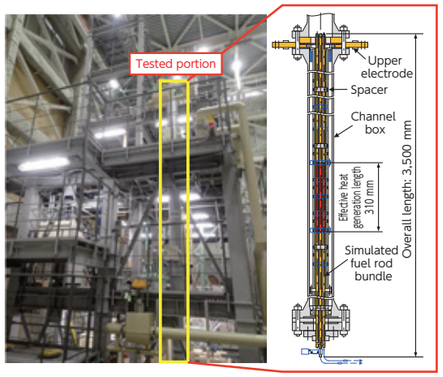
Reactivity Initiated Accident (RIA)
An accident causing the nuclear reactor's output to increase rapidly due to the control rod falling or being projected out and an abrupt reactivity to be initiated within the reactor.

Licensing Analysis Code
A calculation code applied to analytically deriving the technical data required for licensing applications of nuclear power facilities in accordance with law.

Heat Flux
An amount of heat that crosses per unit of area per unit of time (unit example: W/m²)

Hiroki Takiguchi / Takahiro Arai
Thermal Hydraulics Systems Domain, Nuclear Technology Research Laboratory

High-temperature/high-pressure RIA simulator
Obtains data on transient limit heat flux through simulating an instantaneous rapid increase in thermal output.



External appearance of the high-temperature/ high-pressure RIA simulator
A simulator that recreates a RIA in a BWR fuel rod bundle using 9 simulated fuel rods (3 bundles consisting of 3 rods each), with each rod having an overall length of 3.5 m. At a length of 310 mm, the point which equates to an intermediate height, (effective heat generation length), the fuel rods are instantly heated and the boiling/condensing behavior of cooling water is measured with high precision.

Application Examples of Research Results

Through applying transient limit heat flux characteristic and steam-water two-phase flow behavioral data relevant to when a reactivity initiated accident (RIA) is occurring to the licensing analysis code, CRIEPI will help to increase the reliability of safety evaluations and increase the safety of power plants.

Reference: Arai et al., Atomic Energy Society of Japan 2017 Autumn Conference, Lecture no. 1C16 (2017)

Nuclear Power Generation

Development of Flaw Detection Technology with High Accuracy for Dissimilar Metal Welds

Helping to improve the reliability of nondestructive examination through examination of stress corrosion cracking with high accuracy

Background

Ultrasonic testing is a type of nondestructive examination technology used to detect flaws developing in pipe welds in nuclear power plants. When examination is highly difficult or high reliability of examination results is required, a performance demonstration (PD) system is first carried out to verify a technique's ability to detect flaws before the technique is applied to actual examination. Due to the difficulty of measuring the depth of defects in welds between low alloy steel and stainless steel by ultrasonic testing, it was preferable to improve the reliability of examination results through PD system. As the technological foundation necessary to establish PD system, CRIEPI has been developing technologies to fabricate test specimens with stress corrosion cracking (SCC), to evaluate specimen validity and to size defect depth with high accuracy. CRIEPI has already established the technological foundation for detecting flaws from the inner surface of welds, and we are continuing our initiatives for flaw detection from the outer surface also.

Outline of Results

◇ Establishment of technology to fabricate SCC induced test specimens

Leveraging CRIEPI's knowledge and examination technologies relating to SCC, we developed a technology to create an SCC in test specimens simulating the defects found in actual plants whilst controlling the SCC depth. SCCs can be created both perpendicular (axial direction) and parallel (circumferential direction) to the weld line, and have been confirmed as equivalent to the SCCs seen in actual plants (Fig. 1). Furthermore, no noise from dissimilar metal welds was observed to hinder ultrasonic testing. Through these efforts, we successfully established specimen fabrication technology for PD system associated with dissimilar metal welds.

◇ Improvement of accuracy of SCC depth sizing from outer surface of pipes

Regarding SCC depth sizing from the outer surface of pipes, CRIEPI developed a new depth sizing procedure characterized by using a larger ultrasonic phased array probe than was previously used, overall rating of flaw detection results corresponding to two different frequencies and an improved method for identifying the position of the crack opening. The procedure resulted in dramatically improving depth sizing accuracy, such as decreasing depth sizing error to around one-quarter of what it had previously been (Fig. 2).

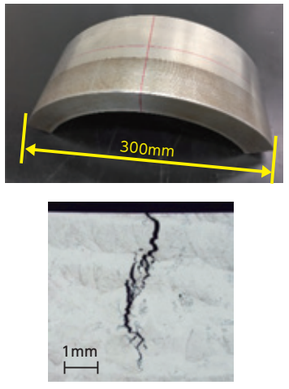


Fig. 1 External view of the fabricated test specimen with SCC (top) and cross-section of the SCC created (bottom)

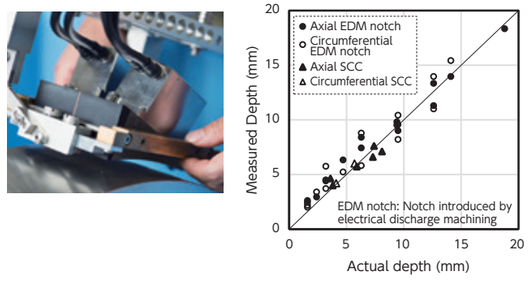


Fig. 2 Ultrasonic phased array probe used (left) and comparison of the depth of SCC in DMW measured from outer surface with actual depth (right)

The mean square root error, which is an indicator of depth sizing accuracy, was around 4 mm in previous studies, however CRIEPI's efforts have reduced this to around 1 mm.

Ultrasonic testing
A nondestructive examination technology that transmits an ultrasonic pulse to detect the location and size of flaws such as internal flaws.

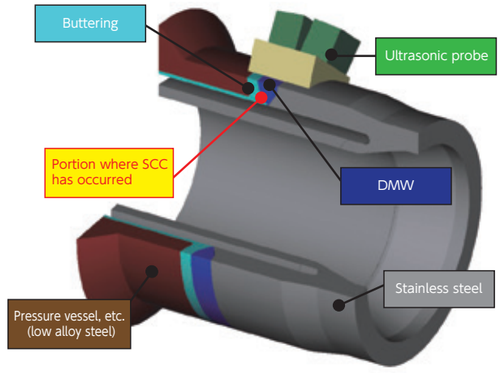
Performance Demonstration (PD)
A method of demonstrating flaw detection ability in a situation resembling an actual scenario including the flaw detection procedure, equipment and technician altogether.

Stress Corrosion Cracking (SCC)
A form of age-related damage that occurs mainly in metal materials such as stainless steel and nickel-based alloys. SCC can occur when susceptible material, tensile stress and corrosive environment are simultaneously present.

Ultrasonic Phased Array
A technology to control the direction of ultrasonic wave propagation and focal position by a specialized ultrasonic probe containing many individual elements that can be pulsed separately with a time delay.

Lin Shan
Structural Materials Sector,
Materials Science Research Laboratory / PD Center

Multi-joint robot scanner
An ultrasonic probe is mounted on an automatically-controlled multi-joint arm and examination is conducted from the outer surface of test specimen.



Conceptual image of ultrasonic flaw detection for dissimilar metal welds (DMWs)

When welding a low alloy steel vessel to a stainless steel pipe, "buttering" is performed on the connecting portion of the vessel side by adding extra weld metal to increase crack resistance, and this is then welded to the pipe side. SCC occurs from inner surface of DMW therefore such SCCs are examined by placing an ultrasonic probe on the outer surface of the relevant portion.

Application Examples of Research Results

By developing the technological foundation necessary to begin performing PD for dissimilar metal welds, CRIEPI will help to improve the reliability of examination results when performing nondestructive examinations that confirm plant integrity.

Nuclear Power Generation

Verification of dose Rate Effect based on the Mechanism of Cell Competition

Contributing to the evaluation of radiation risk based on scientific data

Background

Cancer risk due to low-dose-rate radiation exposure is generally known to be lower than that to high-dose-rate exposure. The results of epidemiological studies of high background radiation areas revealed that the risk of carcinogenesis does not increase at an annual dose rate between around 5 to 10 times greater than the average dose rate of Japanese people. The ICRP proposed "radiation-induced stem cell competition" as one mechanism of the dose rate effect. Unlike high-dose-rate cases in which all cells are irradiated by radiation, low-dose-rate exposure is where both irradiated cells and non-irradiated cells coexist. Radiation-induced stem cell competition is a phenomenon whereby the stem cells that have not been irradiated (non-irradiated stem cells) and the stem cells that have been irradiated (irradiated stem cells) compete with each other and the loser is more likely to be excluded from the tissue. In order to substantiate dose rate effect from a biological mechanism, CRIEPI has created an experimental system that enables the observation of radiation-induced stem cell competition, and is engaging in research activities.

Outline of Results

◇ Quantification of radiation-induced stem cell competition

CRIEPI has established a system to efficiently form organoids (cell cultures formed *in vitro* with a structure representing actual organs) containing stem cells, which are known as the origins of cancer. By using these organoids derived from irradiated and non-irradiated stem cells labeling (identifying) with different fluorescent colors, CRIEPI has developed a technique achieving the visualization and quantification of the stem cell competition that takes place between these two stem cell types. As a result of cocultivating stem cells with different irradiation conditions, it was indicated that the proliferation of irradiated stem cells is difficult (Fig. 1) and we verified feasibility of a hypothesis for the mechanism of dose rate effect.

◇ Gene identification tying dose rate effect to cell competition

Using CRIEPI's radiation sensitivity analysis facility (see p.13 [Major New Research Facilities]), we compared the overall gene expression level of colon stem cells in mice irradiated with the same dose of radiation at differing dose rates and extracted the genes that were specifically activated (switched on) in the case of low-dose-rate only. As a result of introducing such genes to the cultured cells and conducting observations, we observed that the cells which expressed the activated genes were surrounded by the cells that did not, defeated in competition, and then expelled (Fig. 2). These results showed that these genes tie dose rate effect to cell competition.

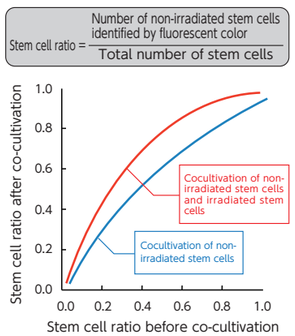


Fig. 1 Comparison of number of non-irradiated stem cells ratio before and after co-cultivation

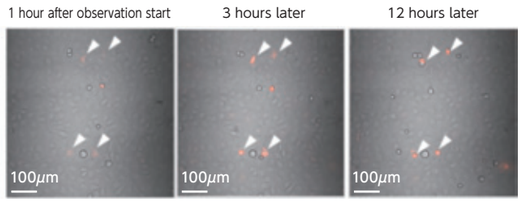


Fig. 2 Cells which express the gene determining dose rate effect are expelled due to cell competition

Identification of the gene groups in the colon stem cells of mice which are activated during low-dose-rate exposure. It was confirmed that genes which did become activated (shown in red) became small spheres and were expelled from the cell population (defeated in competition) (the red color of the cells indicated in the figures using white arrows became more distinct over time.)

ICRP (International Commission on Radiological Protection)
An independent, international academic organization that provides recommendations on radiological protection from an expert standpoint.

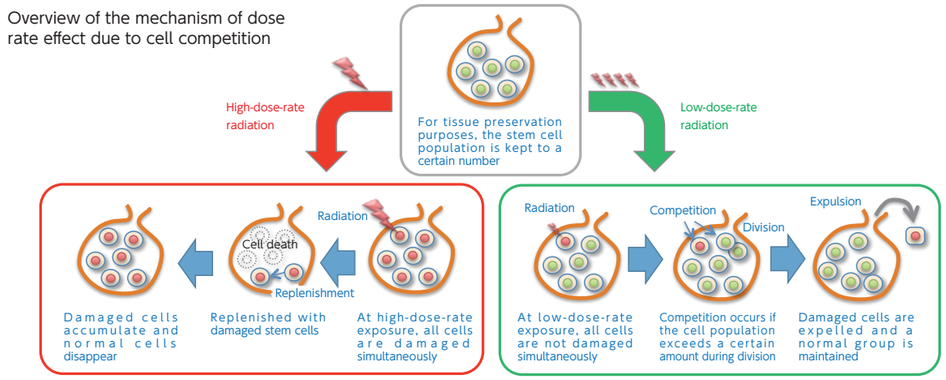
Dose Rate Effect
A state whereby the biological effects are said to be greater if the same amount of radiation is irradiated at a high-dose-rate over a short period of time than a low-dose-rate over a long period rate.

Stem Cell
Cells with the ability to re-produce and replenish cells that have died in order to maintain tissue in which individual cells with a short lifespan are constantly replaced.

Gene Expression
The process whereby genetic information is converted to structure and function within cells. Specifically speaking, gene expression normally indicates protein synthesis based on genetic information.

Stem cell analysis device (cell sorter) A device to analyze and sort the targeted stem cells from a mixed state.

Overview of the mechanism of dose rate effect due to cell competition



Application Examples of Research Results

With the aim of having these results reflected in the next main recommendations by the ICRP, CRIEPI will accumulate more quantitative data relating to dose rate effect due to radiation-induced stem cell competition and convey such data through academic papers, etc.

References: Otsuka et al., J. Radiat. Res., doi: 10.1093/jrr/rrx078 (2017 epub)

2-2. Major Research Results-5

Nuclear Power Generation

Development of a Method to Detect Helium Leaks from Canisters Inside Concrete Casks

Contribution to improved safety and practical application of spent fuel storage

Dry Storage
A method of storing spent fuel in a metal container including inert gas (helium, etc.). A method of storing spent fuel in a water pool is referred to as wet storage.

Concrete Cask
A cylindrical container used for storing spent fuel. A concrete casks is comprised of a stainless steel canister which seals spent fuel and a concrete storage container which shields neutrons. The decay heat of spent fuel is removed by natural convection generated on the canister's surface.

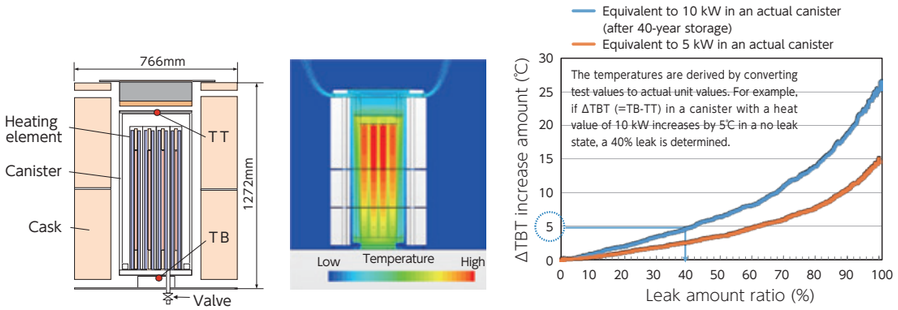
Background

In consideration of the increase in spent fuel due to the restart of nuclear power plant operation and the decommissioning of the reactors, the Japanese government has indicated the need to strengthen storage capacity in its spent fuel countermeasure action plan. Due to the increase in the amount of dry storage, it would be difficult to continue using the metal casks already in practical use alone from the perspective of manufacturing capacity, thus there are expectations for the practical application of a storage system using the concrete casks because of their cost-effectiveness and relatively-quick manufacturing. However, there is concern that in the concrete casks, salt in outside air could cause stress corrosion cracking (SCC) to the canisters during the storage period, resulting in a loss of sealing performance. In order to realize the practical use of concrete casks in Japan, it is expected not only to promote SCC measures, but also to develop a technique to detect even minute leaks in order to improve the safety in case of such a leak event.

Outline of Results

◇ Development of a method to estimate leak amount of helium from canisters

We made a small-scale cask model capable of simulating a heat transfer phenomenon that occurs within an actual canister, and performed a flow experiment and flow analysis simulating a helium leak from a canister (Fig. 1). Based on these results, we measured the increase in the difference between the temperatures at the canister's bottom (TB) and at the canister's lid (TT), so as to develop a method for estimating the leak amount ratio to each heat rate in the canister. Compared to the metal cask in which a pressure gauge is installed, this method realizes low cost and easy maintenance in the concrete cask as a thermo-sensor is installed only on the exterior surface of the canister. Moreover, there is no need to make a hole for installing the thermo-sensor in the canister, therefore no more leak risks are created.



Small-scale Cask Model (1/4.5 scale) | Temperature Distribution based on Analysis | Leak Amount Ratio and Increase in Difference Between Temperatures at Canister Top/Bottom

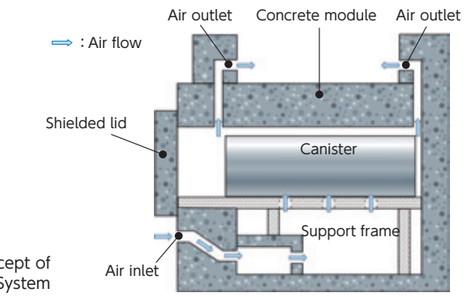
Fig. 1 Small-scale Cask Model, Results of In-cask Flow Analysis, and Leak Evaluation Method

◇ Development of a leak detection method applicable also to horizontal silo storage systems

We performed a leak test/analysis using a small-scale canister model aimed at horizontal storage of the canister (figure on the right-hand page), and selected temperature measurement points to detect the leaks. As a result, in the same way as the vertical storage, it was observed that the temperature at the bottom of the canister increased most, while the temperature at the lid decreased most during the leak. Furthermore, because the temperature of the lower side part increased while that of the upper side part decreased, it was demonstrated that the leak detection using the temperature difference is possible by combining the temperatures of these four measurement points.

Hirofumi Takeda
Nuclear Fuel Cycle Backend Research Center, Civil Engineering Research Laboratory

Small-scale Cask Model
Based on the similarity law of thermal-hydraulics, the flow similar to that in the actual cask during the helium leak is reproducible.



Example of a Design Concept of a Horizontal Silo Storage System

Application Examples of Research Results

By developing the leak detection method with high sensitivity, the safety and reliability of the concrete casks are improved, which leads to their early introduction in Japan. Moreover, if the requirement for SCC inspections is eliminated or mitigated, inspection fees will be significantly reduced.

References: Takeda et al., CRIEPI Research Report N17007 (2018)
Takeda et al., CRIEPI Research Report N17013 (2018)

2-2. Major Research Results-6

Improvement of the Vitrification Process in Spent Fuel Reprocessing Plants

Contributing to enhance the safety of high-level radioactive waste disposal

Nuclear Power Generation

Geological Disposal
A method of burying high-level radioactive waste deep underground and isolating it safely and with certainty over a long period of time so as not to impact the living environments of humans.

Yellow Phase
A water-soluble compound with the primary element of molybdenum formed in the glass melting process. Yellow phase is heavier than molten glass, therefore remains at the bottom of canisters and has the potential to increase the risk of radioactive substances leaching upon geological disposal.

Platinum Group Elements
A group of elements in the periodic table including ruthenium (Ru) and palladium (Pd). Ru and Pd are present in spent fuel and migrate to high-level liquid waste during reprocessing.

Background

The highly-radioactive liquid waste separated in the reprocessing of spent fuel is vitrified to stabilize and geologically disposed of as high-level radioactive waste. However, some elements tend to precipitate in the glass due to limited solubility. The two main types of such precipitates are a crystal phase called yellow phase (YP) which is water soluble and reduces safety upon disposal, and the needle-like crystals of platinum group element oxides that obstruct the stable melting and pouring of glass during vitrification. In order to find a comprehensive solution based on an understanding of the phenomenon, CRIEPI is working to clarify the mechanisms that generate the abovementioned substances.

Outline of Results

◇ Clarification of the mechanism of yellow phase formation

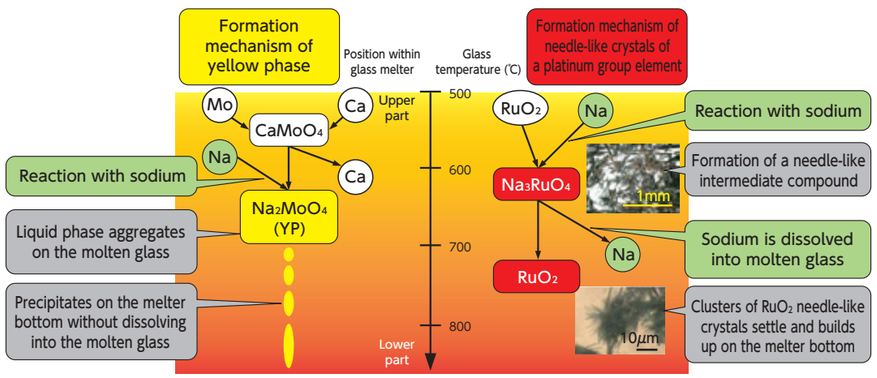
CRIEPI fabricated a small scale glass melter enabling the detailed observation of glass melting behavior and performed experiments. As a result, we clarified that the main element of YP, molybdenum (Mo) primarily forms molten salt with sodium (Na), aggregates, and settles without dissolving into the glass as yellow phase.

◇ Clarification of the mechanism for generating needle-like crystals of a platinum group element

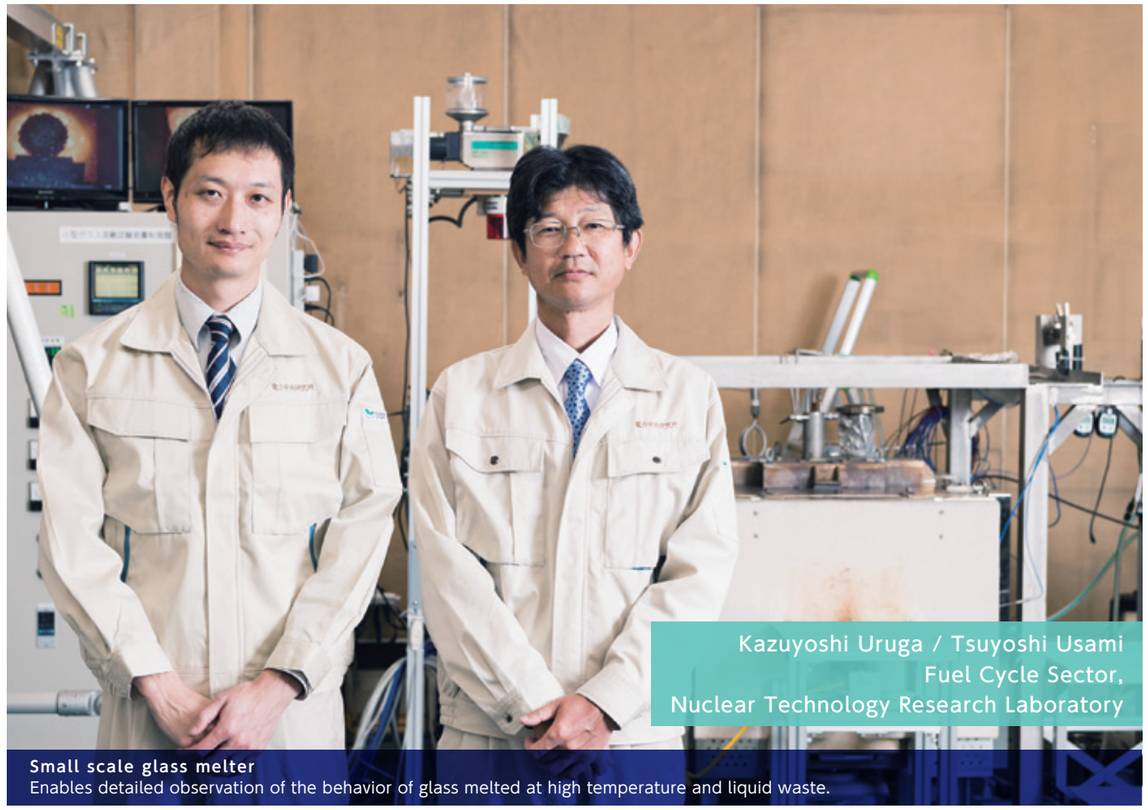
CRIEPI elucidated that ruthenium (Ru) oxide, the main platinum group element in spent fuel, reacts with sodium once to form a needle-like intermediate compound. The sodium in the compound dissolves into molten glass, and needle-like crystals of ruthenium oxide (RuO_2) grow radially.

◇ Proposal of a countermeasure focused on sodium

Since sodium is a highly contributing to the formation of both YP and needle-like crystals of a platinum group element, it was considered be effective in suppressing each substance to dissolve sodium into the glass before it reacts with molybdenum and ruthenium. As one concrete countermeasure, we proposed to enhance the dissolution of sodium into glass by using glass material in a powder form.

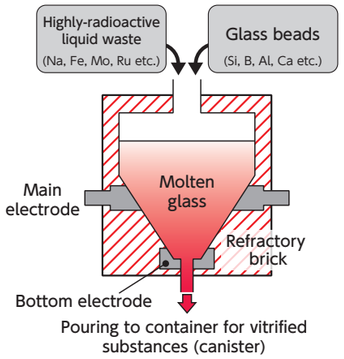


Overview of the formation mechanisms for yellow phase and needle-like crystals of a platinum group element in a glass melter



Kazuyoshi Uruga / Tsuyoshi Usami
Fuel Cycle Sector,
Nuclear Technology Research Laboratory

Small scale glass melter
Enables detailed observation of the behavior of glass melted at high temperature and liquid waste.



Overview of a glass melter
Highly-radioactive liquid waste and glass material are supplied into the glass melter, molten through Joule heating using electrodes then poured into a stainless steel container for vitrified substances (canister) from a nozzle located at the bottom. The temperature within the melting furnace is around 130℃ at the top however the center of the melted glass reaches around 1,150℃.

Application Examples of Research Results

The results of this research have been reflected in the improvement/development plans for vitrification facilities in Rokkasho reprocessing plant. It is anticipated these results will help to achieve stable operation of reprocessing plant and improve safety concerning the geological disposal of radioactive waste.

References: Usami et al., Proc. of Global2015, Paper5186 (2015)
Uruga et al., Proc. of Global2015, Paper5191 (2015)

Thermal Power Generation

Creep Damage
→ See p.8

Proposal of a Method for Planning the Timing of Chemical Cleaning based on Monitoring of Creep Damage Status

Supporting to reduce maintenance costs through the rationalization of chemical cleaning plans for boiler water wall tubes

Background

Chemical cleaning is carried out on the boilers of thermal power plants to prevent creep failure, etc. that occurs in the tube material due to an accumulation of scale on the inside of the water wall tubes over the course of the boiler's operation. The basis of the current chemical cleaning standards for water wall tubes is base load operation from around the 1980s whereby the allowable scale accumulation is determined by the allowable temperature of the tube material which is determined uniformly, therefore the impact of stress and temperature fluctuation during the operation of each individual boiler is not taken into consideration. As a result of investigating the degree of damage to the material used in actual boilers, CRIEPI judged there was potential to rationalize the chemical cleaning standards. In order to secure water wall tube reliability and reduce maintenance costs, CRIEPI proposes a technique to judge the appropriate timing for chemical cleaning based on the individual operating conditions of each boiler.

Outline of Results

◇ Evaluation of creep damage status based on a creep test and metal temperature analysis

In order to assess the status of creep damage in the water wall tubes of actual boilers, CRIEPI performed creep tests on sampled tubes and an analysis of data from the thermometer installed in the fireside of water wall tubes. By using the material strength characteristics obtained in these creep tests and the analysis results of the metal temperature data, it was possible to visualize the creep damage status in relation to operating time. This enables the prediction of the chemical cleaning implementation limit from the status of creep damage in water wall tubes, and determine the minimal required chemical cleaning count until the target life (Fig. 1 (a)).

◇ Proposal of a method for planning chemical cleaning timing

In the method of planning the timing of chemical cleaning proposed by CRIEPI (which uses creep damage status as the index for timing chemical cleaning instead of the conventional scale accumulation amount) if the timing of chemical cleaning is changed based on the minimal required chemical cleaning count, it is possible to quantitatively confirm the impact on creep damage status (Fig. 1 (b)), therefore it is possible to determine a timing for cleaning that minimizes creep damage when the target life is reached and reduce the risk of unscheduled stoppages resulting from the bursting, etc. of water wall tubes.

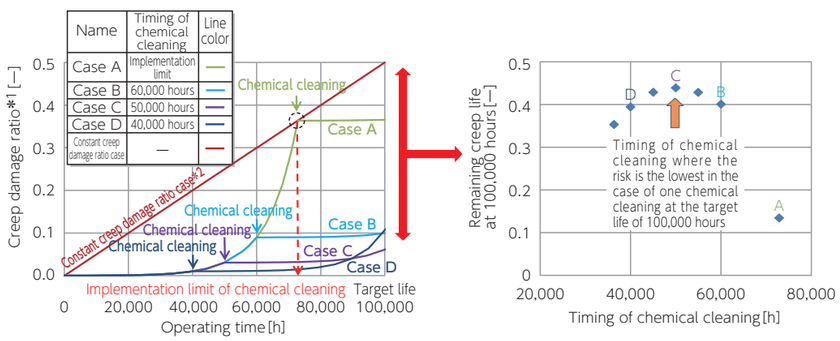


Fig. 1 (a)
Change in creep damage status due to the timing of chemical cleaning

Fig. 1 (b)
Change in remaining creep life due to the timing of chemical cleaning

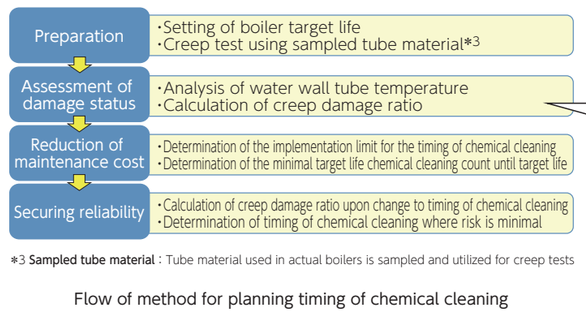
Fig. 1 Change in creep damage status and remaining creep life due to the timing of chemical cleaning

By forecasting the remaining creep life (remaining life) of water wall tubes after cleaning by cleaning cases (timing) until the chemical cleaning limit time, the optimal timing of chemical cleaning can be determined.

*1 **Creep damage ratio** : A value expressing the progress of creep damage whereby new material is 0 and creep rupture is 1.
*2 **Constant creep damage ratio case** : A rupture of the tube material is considered as creep damage ratio 1, while the creep damage ratio limit is set at 0.5. The line along which creep damage of the water wall tubes is hypothesized to progress at a constant rate until target life (100,000 hours in this case) is reached.

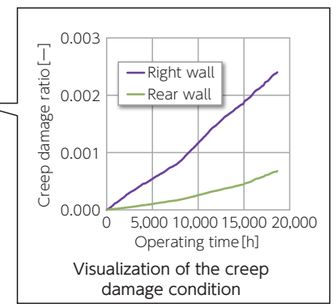
Masahide Yoshida / Masahiko Morinaga
Thermal Power Operation/Maintenance Sector, Energy Engineering Research Laboratory

Miniature creep test unit for inert gas environments
A unit that performs a creep test on test specimens prepared from sampled tube material in an argon gas atmosphere. The results obtained from this unit are utilized for the visualization of creep damage status.



*3 **Sampled tube material** : Tube material used in actual boilers is sampled and utilized for creep tests

Flow of method for planning timing of chemical cleaning



Visualization of the creep damage condition

By focusing on the tube strength/temperature/stress condition of each individual boiler, and using creep damage status as an indicator, the minimum necessary chemical cleaning count until target life is determined (reducing maintenance cost), and the timing of chemical cleaning to minimize creep damage is determined (securing reliability).

Application Examples of Research Results

The method of planning timing of chemical cleaning can be applied to boilers with water wall tubes installed thermometers in the fireside in thermal power plants. By applying this planning method to actual boilers it is possible to achieve monitoring of water wall tube status and support formulation of a chemical cleaning plan aimed at securing reliability and reducing maintenance costs.

References: Morinaga et al., 23rd National Symposium on Power and Energy Systems, Lecture no.D125 (2018)
Morinaga et al., CRIEPI Research Report M15008 (2016)

Thermal Power Generation

Development of a Carbonized Woody Biomass Fuel Capable of High Co-firing Rate in Coal Fired Thermal Power Plant

Contributing to the reduction of CO_2 emissions through the co-firing of carbonized woody biomass fuel and coal

Background

In order to realize the Japanese government's goal of reducing greenhouse gas emissions to 26% by FY2030 (compared to FY2013), there is a need to reduce CO_2 emissions in every field and the technologies to achieve this are currently being developed and verified. Coal fired power plants are promoting the co-firing of carbon-neutral woody biomass with the aim of reducing CO_2 emissions, however the co-firing of wood chips, etc. entails the issues of grindability and supply capability. In order to resolve these issues, CRIEPI is engaging in the technological development of carbonized wood fuel with the aim of expanding the utilization of biomass in coal fired thermal power plants.

Carbonized wood fuel

Improved fuel made from woody biomass that has undergone the pre-treatment of carbonization, molding, etc. Through the improvement process, the grindability, etc. is enhanced, making it possible to use the woody biomass-derived fuel in almost the same way as coal.

Outline of Results

◇ Evaluation of the grindability of carbonized wood fuel

With the aim of reducing CO_2 emissions in coal fired thermal power generation, CRIEPI improved the grindability and calorific value of woody biomass through carbonization and developed a carbonized woody biomass fuel for use at a high co-firing rate in coal fired thermal power generation. Through a grindability evaluation using a roller mill for testing, CRIEPI noted that the power required to grind carbonized woody biomass fuel was almost equivalent to that required for bituminous coal, therefore it would be possible to introduce carbonized woody biomass fuel to coal fired thermal power plants without modifying conventional equipment (coal mill modification, etc.).

◇ Benefits associated with a high co-firing rate of carbonized wood fuel

CRIEPI performed mono-firing tests of coal and carbonized woody biomass fuel respectively on its own coal combustion test furnace. Because carbonized woody biomass fuel contains less nitrogen than coal and hardly any sulfur, there are expectations that the amount of NOx and SO_2 in combustion exhaust gas can be reduced through co-firing in coal fired thermal power plants (Fig. 1). CRIEPI tentatively calculated the CO_2 emissions and combusted coal emissions in the case that carbonized woody biomass fuel was introduced to coal fired thermal power plants. By comparing coal mono-firing and carbonized woody biomass fuel co-firing (co-firing rate of 30% (calorific value basis)), CRIEPI recognized that it was possible to reduce CO_2 emissions by approximately 860,000 tons annually (Fig. 2 (a)). Moreover, due to the fact that carbonized woody biomass fuel contains less ash than coal, (coal: approx. 10%, carbonized woody biomass fuel: 1% or less), the combusted ash output is reduced by around 27,000 tons annually when carbonized woody biomass fuel co-firing is introduced (co-firing rate of 30%), therefore it is possible to reduce the costs involved in ash processing (Fig. 2 (b)).

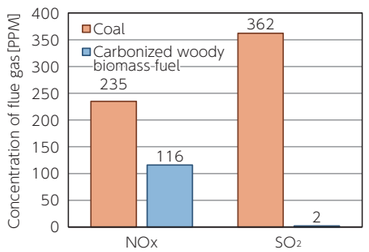


Fig. 1 Comparison of NOx and SO_2 concentration at furnace outlet in the case of mono-firing

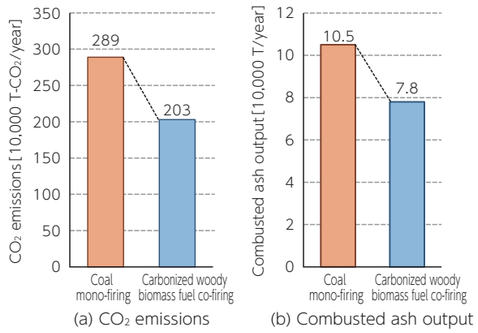


Fig. 2 Tentative comparison for CO_2 emissions (a) and combusted ash output (b) with coal mono-firing and carbonized wood fuel 30% co-firing respectively

Coal fired power plants: Power generation output of 500 MW, power generation efficiency: 40%, annual facility utilization rate: 80%

Maromu Otaka
Energy Platform Creation Sector,
Energy Engineering Research Laboratory

Fuel carbonization test unit
Fabrication test of carbonized fuel derived from raw materials such as woody biomass, etc. and evaluate the carbonization property of the raw material. The manufactured carbonized fuel is utilized as test fuel to evaluate the grindability when mixed with coal and co-firing characteristics.

The manufactured carbonized woody biomass fuel

Application Examples of Research Results

We aim to reduce the CO_2 emissions associated with coal fired thermal power generation through the popularization of carbonized woody biomass fuel suited to a high co-firing rate. This will contribute to the realization of a low-carbon society.

References: Report on the Results of the Low Carbon Technology Research and Development Program FY2016 (Ministry of the Environment)
"Establishment of an energy independent manufacturing process for the expansion of bio-modified coal and development of 100% mono-firing technology for pulverized coal boilers" (2017)
Report on the Results of the Low Carbon Technology Research and Development Program FY2014 (Ministry of the Environment)
"Practical application for a wood biomass improvement process to realize a 30% co-firing rate in coal fired thermal power generation" (2015)

2-2. Major Research Results-9

Hydropower Generation

Development of a Technique for Assessing the Risk of Public Damage Imposed by Hydropower Facilities

● **Supporting assessment of and countermeasures to natural disaster risks**

Kumamoto Earthquakes

The earthquakes that occurred with an epicenter in the Kumamoto region of Japan were termed the "2016 Kumamoto Earthquakes" collectively. Earthquakes of the maximum seismic intensity 7 were observed twice; April 14th and April 16th, and these caused a severe amount of damage, including the collapse of several house, primarily in Kumamoto prefecture.

Background

In light of the lessons learnt in the 2016 Kumamoto Earthquakes, there are now requirements to assess the risk of public damage arising from the damage or destruction of hydropower facilities in the event of natural disasters and the prioritization of natural disaster countermeasures. However, each electric utility manages an enormous number of hydropower facilities, and it is not easy to swiftly assess the risk of public damage for all facilities based on rational criteria. As such, CRIEPI is engaging in the development of a tool enabling the people in charge at each electric utility to simply and rationally assess the risk of public damage of each hydropower facility belonging to his/her company.

Outline of Results

◇ Development of a flooding analysis technique

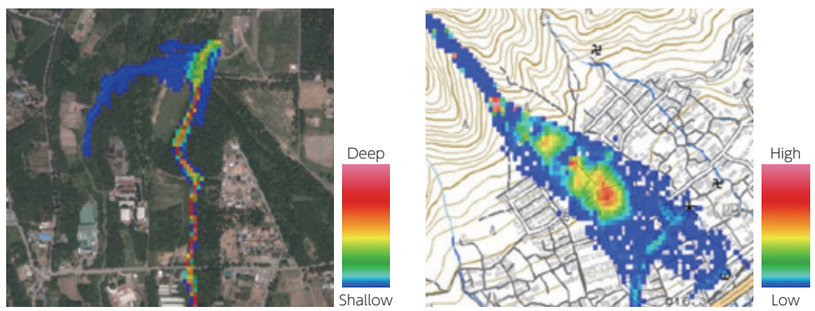
Flooding damage due to water runoff from head tanks and penstock pipes is perceivable as one form of public damage concerning hydropower facilities. As such CRIEPI established a program able to quantitatively analyze the scale of flooding simply by specifying a small number of conditions including runoff amount and runoff time. This analysis can be performed for all regions of Japan using nationwide altitude data prepared by the Geospatial Information Authority of Japan. CRIEPI also established a system to display the calculated results for flood range, etc. on maps so that areas with high risk of public damage can be clearly recognized immediately.

◇ Development of a debris flow analysis

In recent years, a concern has risen regarding debris flow in line with an increase in localized torrential rain. Due to the fact that hydropower facilities are generally located in mountainous regions, debris flow is considered a natural disaster risk that could damage hydropower facilities. As such, CRIEPI has established a program that can simply and rationally analyze debris flow. This program is capable of not only displaying the range impacted by the debris flow, but also the hydrodynamic force of the debris flow at the hydropower facility, therefore it can be used by the persons in charge at each electrical utility for the assessment of the natural disaster risk towards each facility.

Hydrodynamic Force

"Hydrodynamic force" means the force of a fluid and is used as an indicator of the impact fluid has on a structure.

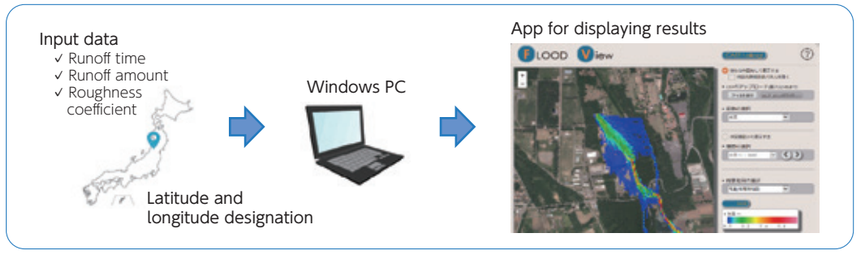


Flood analysis result (left) and debris flow analysis result (right)

The flood analysis result expresses flood depth, while the debris flow analysis result expresses the height of the debris flow deposition height. As the figures show, results can be displayed on either an aerial photo or a figure from the Geospatial Information Authority of Japan.

Ryosuke Arai / Kazuyuki Ota
Fluid Science Sector,
Civil Engineering Research Laboratory

Engages in the development of a technique to assess the natural disaster risk of hydropower facilities.



Program utilization steps

Application Examples of Research Results

The flooding analysis program and debris flow analysis program are adopted by the various electric utilities and are being used for analysis and assessment purposes by the respective people in charge.

References: Arai et al., 13th International Hydroinformatics Conference (2018)
Ota et al., Japan Society of Erosion Control Engineering Journal (2018)

Renewable Energy

Development of Hybrid Power Generation Technology Utilizing Geothermal Energy and Biomass

Contributing to further popularization of geothermal power generation through the feasibility study of the hybrid power generation system

Background

Power generation facilities using renewable energy with minimal CO_2 emissions are being introduced more and more as an initiative aimed at realizing a low-carbon society. According to the "Basic Energy Plan" in Japan, it was set the goal of increasing the capacity of geothermal power facilities from the current 500 MW to 1,500 MW by the year 2030. Since the conventional geothermal power generation system utilizes the geothermal saturated steam with a low calorific value that rises up from production wells, there is a problem that the power generation efficiency was minimal at only slightly over 10%. CRIEPI is promoting the development of a more efficient and economic geothermal power system in order to help expand the regions where geothermal power generation can be applied (This project was supported by New Energy and Industrial Technology Development Organization (NEDO)).

Geothermal Saturated Steam

Steam separated in a moisture separator from the two-phase flow that rises up from underground

Outline of Results

◇ Potential for the introduction of hybrid power generation systems

CRIEPI conducted the feasibility study of a hybrid power generation system (power generation efficiency of 20% or more) combining geothermal energy and biomass as an external heat source. By tentatively calculating the power generation cost, we clarified it would be between 25 and 30 yen/kWh. Since the cost is less than the FIT price (40 yen/kWh) for geothermal and biomass power generation, we can anticipate the commercialization of hybrid power generation systems. We also conducted a survey to evaluate which regions in Japan had high potential as locations for the introduction of hybrid power generation systems. As a result of maps overlay analysis using geothermal resource potential and biomass procurement potential, then refining our results with the conditions of geothermal resources of at least 150℃ as well as biomass reserves of at least 5,000 ton (dry weight)/year, we identified 13 prospective development locations in Japan, including Hokkaido, Tohoku and Kyushu region (Fig. 1).

◇ Small-scale verification test for hybrid power generation system

In the practical application of a hybrid power generation system, one issue that needs to be addressed is blockage of heat exchanger pipes due to scale adhesion of silica or calcium carbonate, etc. contained in geothermal saturated steam. As such, we performed a verification test using an actual-scale superheater pipe at Takigami geothermal power plant where there is a high amount of silica (Fig. 2), and confirmed that problems relating to scale adhesion and corrosion did not occur during steam superheating test, thus clarifying that this system could be realized using current technologies.

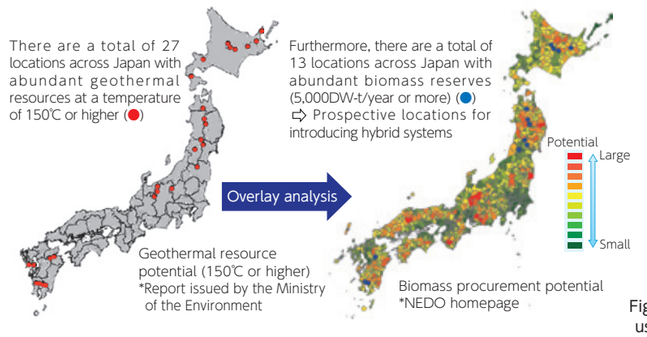
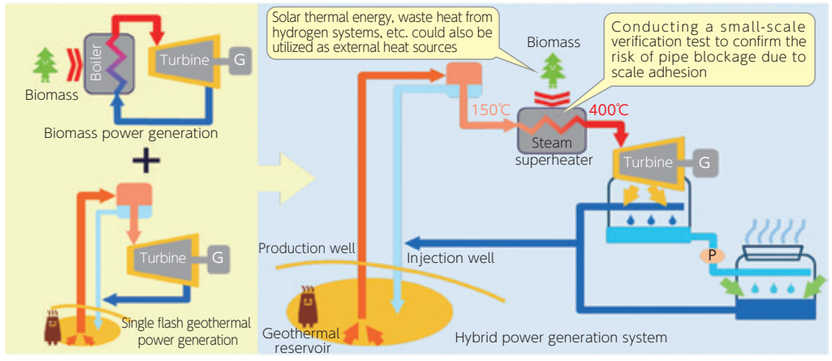


Fig. 1 Prospective locations for introducing hybrid power generation systems

Fig. 2 Small-scale verification test using an actual-size superheating pipe (Kyushu/Takigami geothermal powe plant)

Yoshinobu Nakao
Energy Platform Creation Sector, Energy Engineering Research Laboratory

Geothermal steam superheating test facility
A testing apparatus to observe the status of scale adhesion and corrosion resulting from the geothermal steam superheating test. Geothermal saturated steam provided from the production well is directly supplied to the heat exchanger pipe and can be superheated upto a maximum of 400℃.



Conceptual diagram of a hybrid power generation system utilizing geothermal energy and biomass

Application Examples of Research Results

CRIEPI is contributing to the further popularization of geothermal power generation in Japan through liaising with geothermal power companies, etc. and promoting the introduction of hybrid heat source power generation systems combining geothermal energy and biomass.

References: Nakao et al., GRC Transactions, Vol. 41, p. 794 (2017)

Electric Power Transmission and Distribution

Development of an Accurate Demand and Supply Simulation Model with the Aim of Future Balancing and Frequency Control

Aiming for low-cost and stable operation and control of power systems after the establishment of a balancing market

Background

Japan's current balancing and frequency control is performed by transmission and distribution system operators using control reserves procured through public tenders however, under the Electricity System Reform, with the aim of procuring and operating control reserves more efficiently and economically, a balancing market is planning to be established by the year 2021. This is anticipated to have the effect of reducing balancing and frequency control cost due to the realization cross-border balancing control. Meanwhile, for stable operation and control of power systems, it is necessary to design the scheme with consideration to the technical challenges. In order to realize low-cost and stable operation and control of power systems in the future, CRIEPI has identified the technical challenges accompanying the establishment of a balancing market and studied countermeasures thereof.

Outline of Results

◇ Development of an accurate demand and supply simulation model

CRIEPI developed a demand and supply plan model and an automatic generation control model simulating precisely generation dynamic behavior, the centralized automatic generation control function, etc. in an actual power system. Through simulations utilizing these models, CRIEPI elucidated the technical challenges and cost reduction benefits due to the establishing balancing market in relation to load frequency control (LFC) and economic dispatching control (EDC).

◇ Identified the technical challenges of load frequency control (LFC) based on merit order and evaluating the operating cost thereof

When secondary control reserves (SCRs) for LFC were activated based on merit order (MO), although the operating cost (energy price) of SCR decreases, the area requirement (AR) increases compared to the current level (pro-rata activation scheme). Here, CRIEPI quantitatively indicated that by performing LFC based on MO that also considers the ramp rate of generator output, the operating cost of SCR can be reduced while keeping the AR around the same level as it is currently, therefore low-cost and stable supply is possible (Fig. 1).

◇ Evaluated operating cost of tertiary control reserve based on cross-border balancing

By performing a 2-area cross-border balancing simulation targeting tertiary control reserve (TCR), we obtained results which showed that, compared to balancing in each control area, there was hardly no increase in AR due to changing tie-line power flow reference and both the operating cost and activation volume of TCR were reduced (Fig. 2).

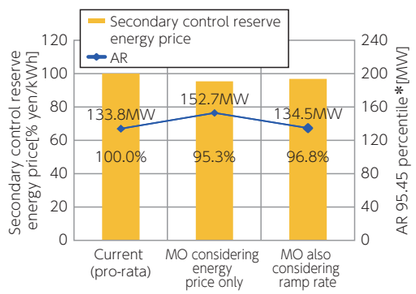


Fig. 1 LFC simulation results

For the current LFC, SCR is activated based on the ramp rate pro-rata scheme. Meanwhile, in the case of MO-based LFC, SCR is activated sequentially starting from the lowest kWh unit price.

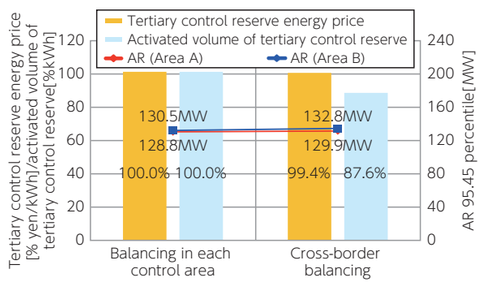


Fig. 2 Results of a cross-border balancing simulation

By utilizing low-cost tertiary control reserve in a wide area (Area A + Area B), the energy price of the activated tertiary control reserve is reduced. Moreover, the activated volume of the tertiary control reserve is reduced by imbalance netting.

∗ **Percentile** : The relevant percent when data is arranged in order from smallest to largest.

Load Frequency Control (LFC)
In order to maintain a balance between supply and demand within each control area as well as the system frequency within the synchronous area, control generator output based on secondary control reserves that are under automatic control.

Economic Dispatching Control (EDC)
Controls generator output within the certain limits and maintain a balance between supply and demand with less fuel cost.

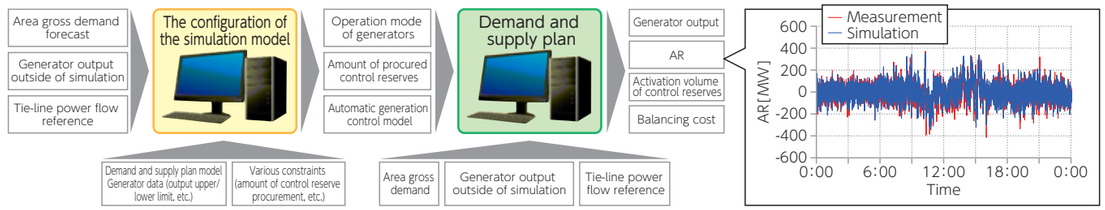
Merit Order (MO)
Here, merit order refers to the energy price arranged in order from least to most expensive.

Secondary Control Reserve
Here, secondary control reserve is utilized by LFC and can provide the full offered bid volume at the latest 5-minute after its activation.

Area Requirement (AR)
The difference between the load demand and power supply within each control area.

Tertiary Control Reserve
Here, tertiary control reserve is utilized by EDC and can provide the full offered bid volume at the latest 15-minute after its activation.

Supports the realization of low-cost and stable operation and control of power systems through utilizing simulations.



Overview of simulation using the power generation plan model and supply/demand control model

Application Examples of Research Results

In regards to the establishment of a balancing market by around the year 2021, the Japanese government, Organization for Cross-regional Coordination of Transmission Operators, etc. can leverage these research results when designing the scheme, therefore a low-cost and stable operation and control of power systems are anticipated after the balancing market is established.

References: Tokumitsu et al., CRIEPI Research Report R17006 (2018)

Electric Power Transmission and Distribution

Development of Image Processing Technology and an AI Technique to Support the Maintenance of Transmission Towers

Contributing to labor-saving in transmission tower maintenance with a simple deterioration judgment support tool

Background

Electric power companies apply anti-corrosive agent to transmission towers with advanced corrosion as a measure to alleviate the effects of tower aging. This means that, out of a vast number of transmission towers (average of 24,000 towers per electric power company) there is a need to identify those which require application of anti-corrosive agent and efficiently determine an order of priority. However, often the extent of corrosion is ranked through visual judgment based on photos of tower steel, therefore there is the issue of not only extensive labor but also allocation of priority depended on an subjective evaluation. With the aim of achieving labor-saving in transmission tower maintenance, CRIEPI has combined image processing technology and an AI technique to develop a technology capable of automatically judging the deterioration ranking of transmission towers from aerial photographs taken from helicopters, etc. and support the determination of an order of priority for anti-corrosive agent application.

Outline of Results

◇ Extraction of transmission tower portion from aerial photos and determination of deterioration ranking

The extent to which corrosion has progressed is judged from photographs of transmission tower steel, however all other portions of such photographs are not required as they merely create noise. CRIEPI has developed an image processing technology to extract only the transmission tower portion through comparison of a transmission tower aerial photo and 3D structural model (Fig. 1). At the same time, we have also developed an AI technique to determine the corrosion progression ranking for each portion of the tower based on the extracted transmission tower image. Through an overall assessment of corrosion progression rankings based on this AI technique, it is possible to judge the deterioration ranking of a transmission tower and easily allocate an order of priority for anti-corrosive agent application based on the judgment results.

◇ A prototype of the support tool for judging ranking of transmission tower deterioration

Based on the abovementioned image processing technology and AI technique, CRIEPI developed a prototype of the simple deterioration judgment support tool. Using this tool and aerial photographs of two actual transmission towers, we verified the entire process of transmission tower extraction, corrosion progression ranking judgment and tower deterioration ranking judgment. Moreover, as a result of removing the portions with 20 × 20 pixels from the two transmission tower extracted photographs (approximately 1,900) and judging the respective corrosion rankings across five ranks, we confirmed an accuracy rate of around 83%. Moving forward, we will investigate the practical level for judgment accuracy, further raise accuracy and create a tool to support the judgment of deterioration.

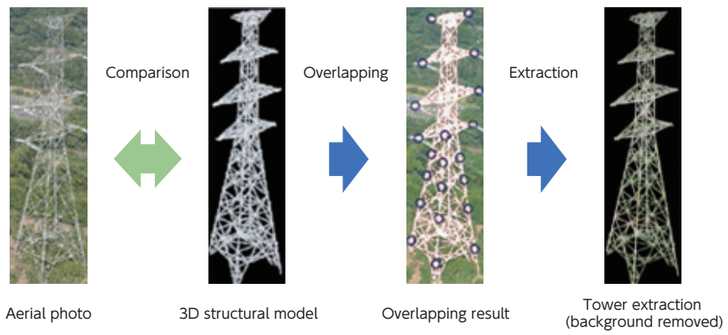


Fig. 1 Extraction of a tower image using image processing technology

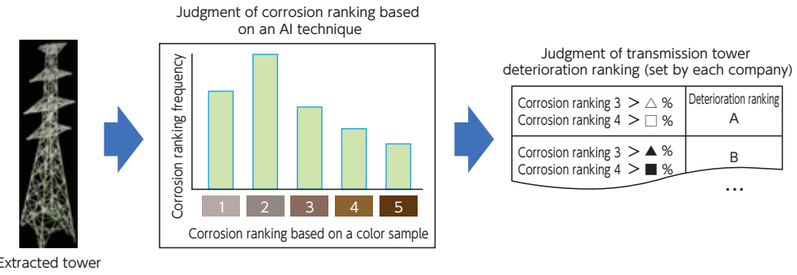
The round circles in the above figure are the points that were specified for the overlapping of the aerial photo and 3D structural model

3D Structure Model

A 3D skeleton diagram used to investigate the strength of a transmission tower relative to its load. Created from structural drawings (blueprints) of transmission towers.

Ryuichi Ishino
Digital Transformation Unit, Energy Innovation Center

Based on an image processing technology and AI technique, engages in the development of a support tool helping to save labor in the maintenance of transmission towers.



Judging deterioration rank in order to determine the order of priority for applying anti-corrosive agent to transmission towers

Application Examples of Research Results

Using the results of this research, it is possible to significantly reduce the labor required to judge the necessity for anti-corrosive agent application performed by electric power companies on transmission towers. Moreover, whereas previously individual workers determined the order of priority for application work based on their subjective judgment, the support tool developed by CRIEPI enables objective and rational determination, thus increasing the ability to explain the decision behind whether to apply anti-corrosive agent or not.

References: Ishino et al., CRIEPI Research Report C17013 (2018)

Development of a Technology to Remotely Measure the Salt Density of Insulator Surfaces using a Laser

Contributing to higher efficiency and speed in transmission tower maintenance/inspection work through remote measurement from the ground

Electric Power Transmission and Distribution

Brush-Wipe Method
A method to measure the salt density of insulator surfaces by washing the surfaces using a brush, etc. containing distilled water then measuring the electrical resistance of the water.

Laser-Induced Breakdown Spectroscopy (LIBS)
A technology to identify and quantify elements deposited on or contained in the target by focusing laser beams on the target to generate plasma, then diffracting the light emitted from the said plasma.

Cross Arm
Steel brackets used to mount insulators, etc.

Contamination classification for salt damage
The pollution of insulators is categorized into multiple levels depending on the salt deposit density and these levels are called contamination classification. In regards to power transmission facilities, excluding cases of direct exposure to seawater spray, the contamination classification of A (0.038 mg/cm²) to D (0.55 mg/cm²) are used as the maximum speculated salt deposit densities.

Background

Insulators are essential for retaining insulation in electric power transmission and distribution equipment, however are susceptible to salt deposit due to being located outdoors and this can lead to transmission accidents stemming from a reduction in insulation performance as a result of high salt density. As such, measuring the salt density of insulator surfaces is important in preventing transmission accidents. Currently, salt density is measured manually using a brush-wipe method, etc. With the aim of significantly reducing the time required to perform measurement tasks, CRIEPI is engaging in research of Laser-Induced Breakdown Spectroscopy (LIBS), which enables measurement to be performed remotely.

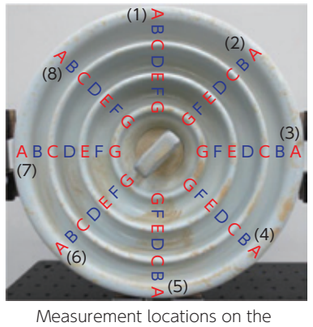
Outline of Results

◇ Remote measurement of salt density with a distance of 20 meters

In order to apply LIBS to the insulators mounted to transmission towers, we performed remote measurements with a distance of 20 m, which is equivalent to the standard cross arm height of 66 kV transmission towers. In this experiment, we irradiated a flat sample to which salt had intentionally been deposited with a laser beam and elucidated how the emission intensities of sodium (Na) and chlorine (Cl), the main ingredients of salt, are related to salt density using emission analysis. From this relationship, it is possible to find salt density based on emission intensity. Conventionally, emission intensities of so called “sodium D lines” were primarily used, however CRIEPI adopted different sodium and chlorine lines to measure wide concentration ranges up to high densities. As a result, we demonstrated that it was possible to measure salt densities ranging from 0.009 to 0.7 mg/cm², which covers almost all contamination levels in Japanese contamination classification for salt damage of power transmission facilities.

◇ Salt density distribution measurement for insulators

Actual insulators are not flat, rather have a complex shape, therefore the salt density distribution is not always uniform. Uneven distribution may lead to formation of local conduction paths. As such, we performed a qualitative salt density distribution measurement on insulators as a preliminary experiment. For the sample, we assumed the emission intensity would be high at the tip of the rib due to salt water concentrating and drying here as the insulator was dipped in salt water, then left to dry in a position where the side with the rib was facing downwards. Experimental results followed our above assumption, and we showed the potential to identify salt density by local concentration level (Fig. 1).



Measurement locations on the rib side of ceramic insulator

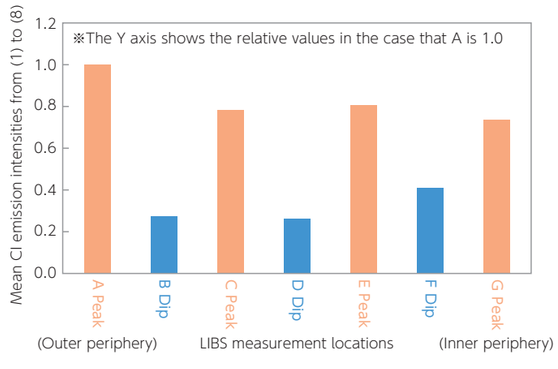
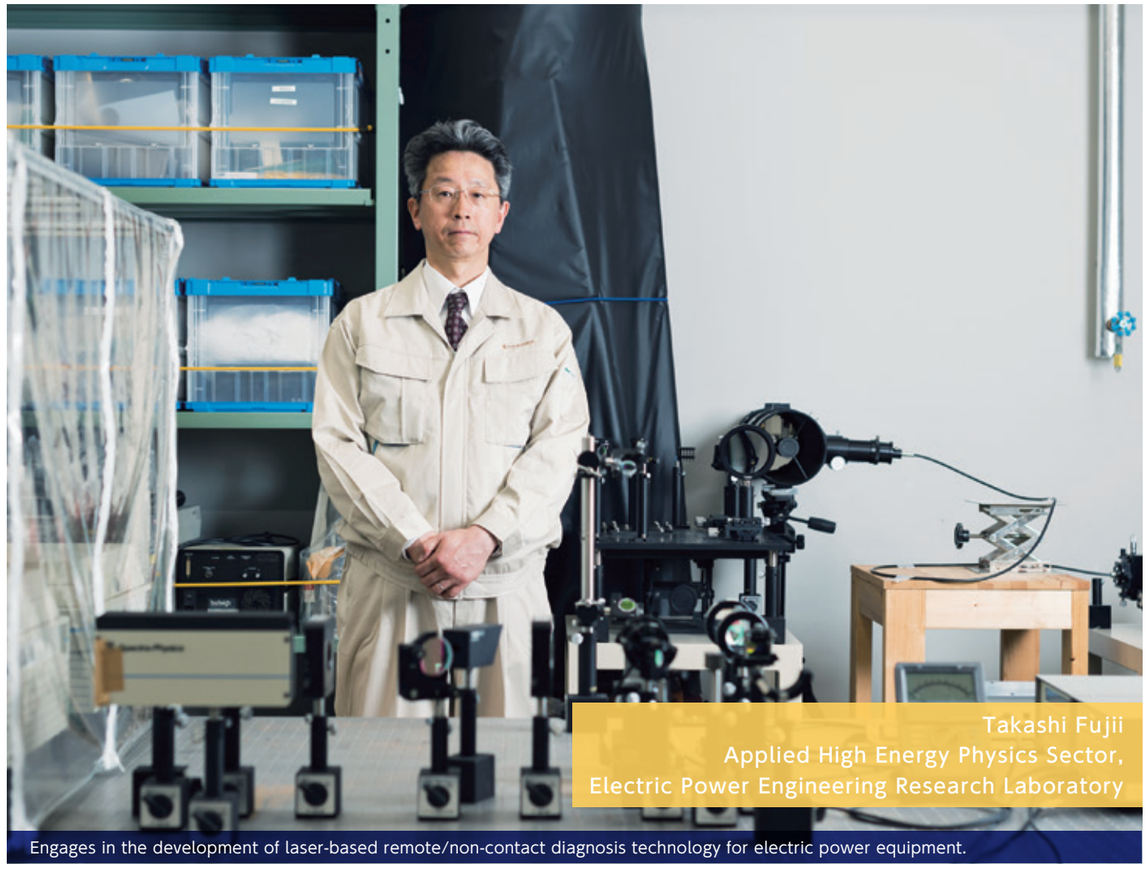


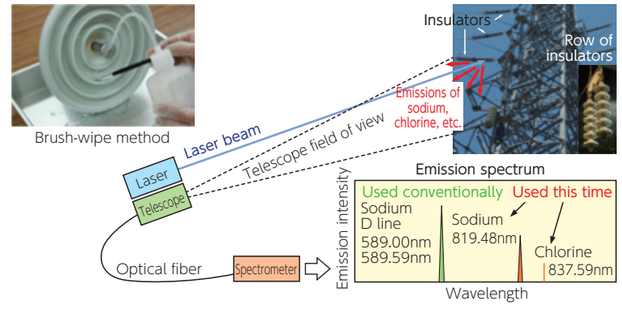
Fig. 1 Example of a qualitative salt density distribution measurement on the rib side of an insulator



Engages in the development of laser-based remote/non-contact diagnosis technology for electric power equipment.

Conceptual diagram of salt density measurement for insulator surfaces using LIBS

In contrast to the brush-wipe method, whereby analysis is performed primarily after retrieving the insulators installed for monitoring purposes, the LIBS method enables remote measurement from the ground, therefore the insulators can be measured swiftly on the spot with no need for retrieval. Moreover, LIBS also enables charged insulators to be measured safely without the need to gain close proximity to live wires.



Application Examples of Research Results

The technology developed through this research is anticipated to realize the swift measurement of salt density on the surfaces of insulators used in power conversion equipment such as transmission towers. Moreover, LIBS is able to simultaneously measure various substances therefore has the potential to be applied to the evaluation of insulator pollution due to various salt types, such as volcanic ash or factory flue gas.

Reference: Fujii et al., CRIEPI Research Report H17007 (2018)
CRIEPI TOPICS Vol. 25 (2018)

Electric Power Transmission and Distribution

Establishment of a Test Method for Evaluating the Immunity of Drones in Electromagnetic Environments

Contributing to the safe utilization of drones for maintenance and inspection work on overhead transmission lines, etc.

Background

In recent years there has been an increasing amount of interest in the industrial utilization of drones. Even in the electricity business, there are expectations of drones being utilized for the maintenance and inspection of overhead transmission lines, which would otherwise require work-at-heights, the confirmation of situations in hazardous regions during disasters, confirmation of equipment status, etc. Recently, drones are equipped with numerous sensors such as GPS and speed sensors, as well as the electronic circuits and wireless communication equipment to control these sensors and motors, therefore when using such drones in close proximity to power equipment such as overhead transmission lines, there is a need to clarify the impact of the electric or magnetic fields emitted from such power equipment on the drone. CRIEPI is engaging in research to evaluate the tolerance of drones in electromagnetic environments (electromagnetic immunity).

Electromagnetic Immunity
Ability of an electrical device to withstand exposure to electronic stress (electric field, magnetic field, etc.)

Outline of Results

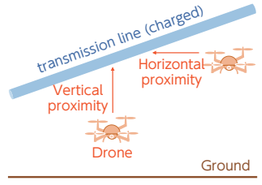
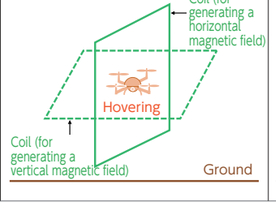
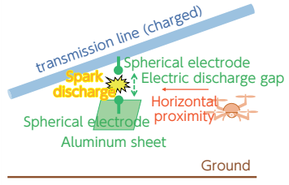
◇ Establishment of an electromagnetic immunity evaluation test method

As the electromagnetic fields for evaluation of electromagnetic immunity, we selected three types; namely a commercial frequency electric field, a commercial frequency magnetic field and an electromagnetic field caused by spark discharge. We then conceived evaluation methods for the impact of these electromagnetic fields, respectively. Moreover, utilizing the high-voltage facility at CRIEPI's Shiobara Testing Yard. we built an evaluation device able to accommodate super-high-voltage power transmission up to 500 kV, the highest voltage class in Japan (Table 1). This has made it possible to quantitatively evaluate the electromagnetic immunity of drones. Moving forward, with the aim of supporting utilization of drones in the maintenance and inspection of overhead transmission lines, we will accumulate data and better clarify drone immunity level.

Commercial Frequency (no.)
This is the frequency of the commercial power source, and is either 50 Hz or 60 Hz in Japan.

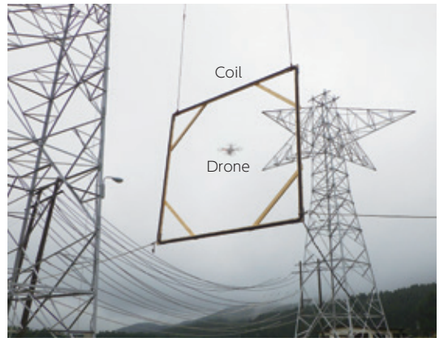
Spark Discharge
Gas electrical discharge accompanied by a large noise and spark. It is extremely rare for spark discharge to occur on power facilities however the electromagnetic field generated by a spark discharge includes several GHz bands used in communication, therefore there is concern this would impact the wireless communication used by drones.

Table 1 Evaluate test method for drone electromagnetic immunity

Target	Commercial frequency electric field	Commercial frequency magnetic field	Electromagnetic field caused by spark discharge
Content	Exposure to the electric field recreating a state in close proximity to a transmission line	Exposure to the magnetic field generated from a large coil	Exposure to the electromagnetic field caused by spark discharge
Method	1. Gradually move the drone closer to the charged transmission line 2. Record the electric field intensity where abnormalities were observed in the drone	1. Have the drone hover at the coil center and gradually increase magnetic flux density 2. Record the magnetic flux density where abnormalities were observed in the drone	1. Gradually move the drone closer to the electric discharge gap of the charged transmission line 2. Record the information where abnormalities were observed in the drone (intensity of electric discharge, etc.)
Equipment schematic			

Kiyotomi Miyajima
Lightning and Electromagnetic Environment Sector, Electric Power Engineering Research Laboratory

Evaluates the impact of electromagnetic fields generated from overhead transmission lines and other power facilities on drones.



Example of evaluation test for drone horizontal magnetic field immunity

The coil is suspended vertically relative to the ground and the magnetic flux density is varied by changing the electric current put through the coil. By doing this, it is possible to evaluate the immunity against the horizontal magnetic field of a drone hovering at the coil center.

Application Examples of Research Results

Contributing to establishment of guidelines for selection of drones suitable for the maintenance and inspection of overhead transmission lines and other power facilities, as well as the revision of national guidelines, regulations, etc. foreseeable in the future.

Reference: Miyajima et al., CRIEPI Research Report H17010 (2018)

Elucidation of the Cable Surf-Riding Phenomenon of Underground Power Cables

Contributing to the soundness diagnosis and optimization of maintenance standards for the increasing number of aged underground power transmission facilities

Electric Power Transmission and Distribution

Surf-riding Phenomenon

A phenomenon whereby the power cables inside a pipeline buried under roads move primarily in the direction of vehicle travel due to the passing of vehicles on the road.

Background

When the surf-riding phenomenon occurs on underground power cables, the cable primarily moves in the direction of vehicle travel (Fig. 1) and countermeasures must be implemented for this due to concern it will have the cause of cable buckling or reducing the insulation performance of the cable junctions. To date, several techniques for forecasting or combating this surf-riding phenomenon have been proposed however these have all been experimental with limited scopes of application or minimally effective due to using countermeasures where the movement of cables is forcefully restrained without clarifying the mechanism. Therefore, there is a need to establish a highly-versatile evaluation method and more effective countermeasure based on the mechanism of the surf-riding phenomenon.

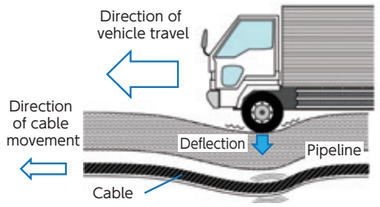


Fig. 1 Conceptual diagram of the cable surf-riding phenomenon

Outline of Results

◇ Development of a model test apparatus for recreating the surf-riding phenomenon

We developed a small model test apparatus of around one-tenth of actual size in order to simulate the surf-riding phenomenon of power cables (Fig. 2). In this apparatus, a PVC pipe assuming an underground pipe line is buried and a tire is run along the road surface whilst controlling overburden load and the cable moves inside the PVC pipe. Using this apparatus, various installation environments can be reflected, such as the road traffic environment (traffic volume, vehicle weight, speed, etc.) and ground conditions.

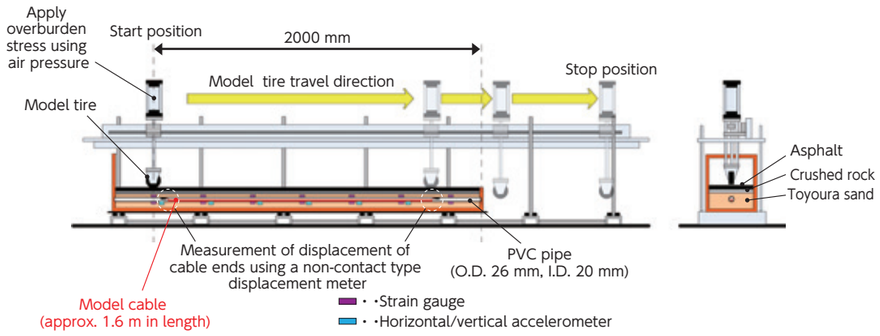


Fig. 2 Small model test apparatus (approx. 1/10 scale)

◇ Development of a surf-riding phenomenon evaluation model

CRIEPI developed an evaluation model that taking account of most of the factors relating to the surf-riding phenomenon. Moreover, through a sensitivity analysis using the evaluation model, we indicated that the main factors causing surf-riding phenomenon are the friction between the pipeline and cable, and the vertical/horizontal vibration of the pipeline. As a result, we clarified that partial installation of high-friction material around cables and the use of anti-vibration rubber are promising as countermeasures with greater effectiveness.

Taiki Yoshida / Kunihiko Nakamura
Earthquake Engineering Sector, Civil Engineering Research Laboratory

Cable surf-riding test facility
Able to recreate the surf-riding phenomenon occurring on underground cables in various installation environments.

Mock tire used to run over the road surface in the small, indoor mock-up testing facility

Application Examples of Research Results

By using the evaluation model proposed by CRIEPI, it is possible to easily judge whether or not countermeasures to alleviate cable surf-riding are necessary in the design phase. Moreover, it is possible to select a more suitable countermeasure for existing cables on which the surf-riding phenomenon is occurring by considering the unique installation environments and cable property values. Through these, compared to previous post-event countermeasures, more rational investment plans can be established as it is possible to conduct prior investigations into countermeasures optimal for the actual circumstances.

References: Yoshida et al., CRIEPI Research Report N17014 (2018)
Nakamura et al., CRIEPI Research Report N16014 (2017)

Establishment of a Security Testbed Targeting Power Grid Control Systems and Substation Automation Systems

Helping to improve the response capability to cyber-attacks targeting power grid control systems

Electric Power Transmission and Distribution

IEC 61850
An international standard relating to smart grids. The original aim of this standard was the standardization of information exchange between intelligent electronic devices (IED) in a substation.

Incident
In general "incident" refers to happenings, events and accidents. In the context of information security, incident refers to events threatening a computer or network's security.

Intelligent Electronic Device (IED)
A general-purpose device with protection, control and measurement functions that is programmable and therefore able to flexibly respond to various needs.

Station Bus
A network for use within substations adopting IP transmission to achieve connectivity of IEDs between different vendors. Mainly communicates operation commands, electrical current/voltage values, status information, etc.

Background

In recent years, the power grid control systems overseas applying the international standard of IEC 61850 are being subjected to cyber-attacks in addition to situations triggering large-scale power outages. Even in Japan, in order to achieve low-cost and interoperability between different vendors, monitoring and control devices complying with IEC 61850 are under development. In order to test the effectiveness of security countermeasures and the feasibility of cyber-attacks similar to those occurring overseas, as well as implement incident response drills for personnel working with control systems, there is a need to establish a security testbed which is both low cost and features the necessary functions.

Outline of Results

◇ Establishment of a cyber security testbed

CRIEPI established a security testbed within a substation comprising of intelligent electronic devices (IED), an operator console (HMI), a telecontrol unit (TC) and a station bus required for communication between these components. This environment is capable of recreating control logic and communication stipulated by IEC 61850.

◇ Implementation of a function to detect/block communication in accordance with the IEC 61850 standard

CRIEPI implemented the station bus with a function to detect and block communication in accordance with IEC 61850. By using this function, it is possible to simulate the communication failure, etc. caused by a cyber-attack without modifying IED or HMI, and monitor the communication during such times. Moreover, this function can also be utilized as a security countermeasure as it is possible to detect and block communication from unauthorized terminals.

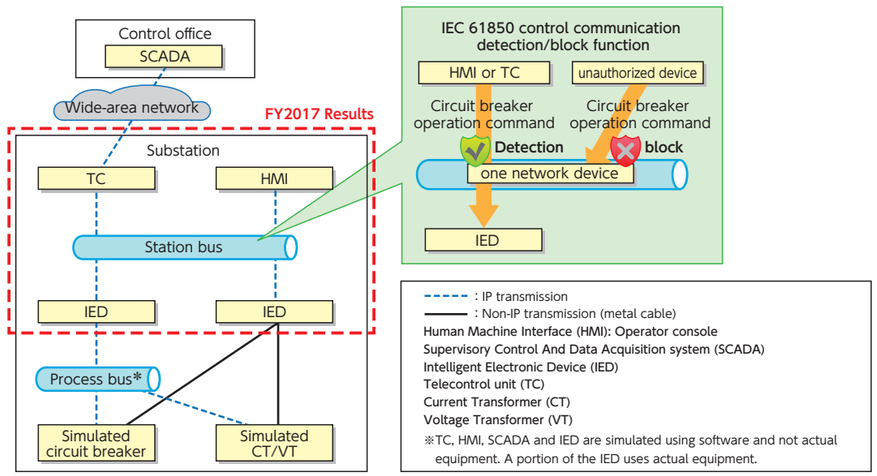
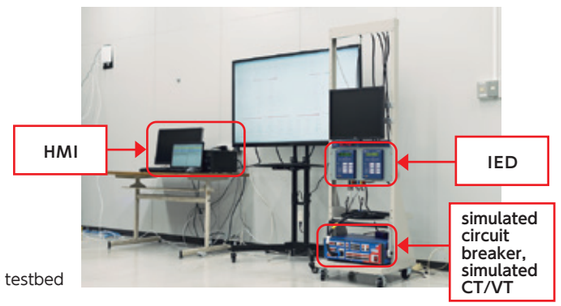


Fig. Diagram of security testbed for a power network control system

* **Process bus** : A communication network utilizing IP/Ethernet transmission in order to use less cables for control between the IED and main circuit devices. Electrical current/voltage values, trip signal, status information, etc. are communicated.

Noriyuki Ueda
Communication Systems Sector,
System Engineering Research Laboratory

Tests the impact of cyber-attacks on power grid control systems in a security testbed, as well as the effectiveness of security measures.



Main components of the security testbed

Application Examples of Research Results

This testbed is independent of general networks therefore it is possible to execute cyber-attacks using foreseeable scenarios in addition to known forms of cyber-attacks, and verify the impact of such cyber-attacks on power grid control systems as well as the effectiveness of related security measures. Furthermore, by carrying out practical security exercises for various scenarios, CRIEPI is helping to improve incident response capability for utilities.

References: Ueda, GS5-3,Proceedings of annual conference of Electronics, Information and Systems Society, IEEJ, 2017
Shimada, TC10-6, Proceedings of annual conference of Electronics, Information and Systems Society, IEEJ, 2015

Utilization of an AI Technique for a Maximum Demand Alert Service

Assisting reduction of maximum demand based on demand forecasting

Customer Services

Assisting consumer's energy-saving activities utilizing an AI technique.

Contract demand

Usually a consumer is charged a basic fee for electricity proportional to the contract demand (maximum 30 minute demand value in the most recent 12 months). This type of contracts are usually applied to high voltage (over 6,000 V) consumers like business-use buildings or commercial facilities.

30-minute Demand

Mean power consumption in a 30-minute interval (calculated once every 30 minutes). The largest 30-minute demand within a month is defined as the maximum demand for that month.

Linear Regression

In statistics, estimation of a model (function) to describe a relationship between a variable that should be predicted (explained variable) and variables that explain the explained variable is called "regression analysis." It is further specified as "linear regression" if a linear function is used for the model. For the electricity demand forecasting, the explained variable is the demand data in the future and the explanatory variables are the input data in the past.

Regression Coefficient

Coefficients for regression equation correspond to gradient of the function for a linear regression equation. The regression coefficients are determined by minimizing sum of the errors of past forecast results in the simplest method.

Background

In many cases, corporations or public organizations consume electricity so as not to exceed contract demand, which is determined by their maximum 30-minute demand recorded in the most recent 12-month periods. Thus, reduction of maximum peak demand is economically beneficial for the consumers. CRIEPI developed an AI-based method to forecast 30 minute demand and a prototype of services for consumers where email alerts are sent when the forecasted demand exceeds a predefined precaution level.

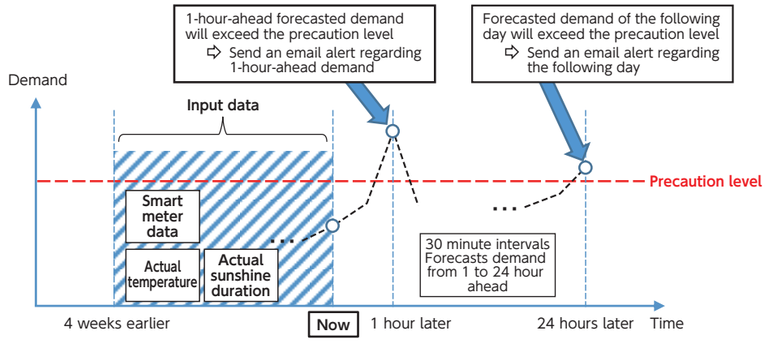
Outline of Results

◇ A method to predict 30 minute demand

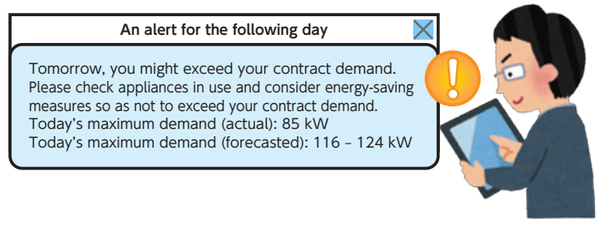
The proposed method predicts 30 minute demand from one hour to 24 hours ahead based on smart meter data and weather data from the Meteorological Agency. The predictions are based on a simple linear regression model which describes the relationship between input data in the past and demand data in the future. CRIEPI developed a method to search a combination of coefficients for the regression model by applying an AI technique, which enables to prevent large errors in maximum demand prediction using limited past data.

◇ Alert service for exceedance of precaution level

CRIEPI investigated a framework for a service utilizing the 30 minute demand prediction. We devised an alert service system to notify users by emails if the forecasted demand exceeds the precaution level. This system enables users to prioritize which minimum oversights of actual exceedances of the precaution level or minimum false alerts. Users can also choose "1-hour-ahead alert" that sends email alerts if the 1-hour-ahead forecasted demand exceeds the precaution level, or "1-day-ahead alert" that sends email alerts using the 24-hours-ahead forecasted demand, or somewhere between them. Using an actual data set, the forecasting accuracy how many exceedances of precaution level the alerts covered was 74.8% for 1-hour-ahead forecast without an interval and 96.7% for 24 hours ahead forecast with an interval (without distinguishing in which time of the day the demand exceeded the precaution level).



Conceptual diagram of the alert service system



Conceptual diagram of email alerts

Application Examples of Research Results

CRIEPI is promoting activities for energy-saving and cost-saving by incorporating this alert service into our energy-saving advice report system for SMEs that we previously developed.

References: Komatsu et al., CRIEPI Research Report C17007 (2018)
Komatsu et al., CRIEPI Research Report Y15004 (2016)

Environment

Evaluation of the Biological Effects of the Magnetic Field Generated by Induction Heating (IH) Cookers

Aiming to improve understanding of health risks relating to IH cooker-generated magnetic fields

Background

Recently, there are an increasing number of electronic devices utilizing intermediate frequency magnetic fields such as IH cookers and wireless power transfer systems. In order to be able to use these devices safely, there is a need to scientifically elucidate the effect of magnetic fields regarding the health risk to humans. In the research conducted around the world to date, not enough biological evidence has been accumulated in regards to the health risks of magnetic fields. CRIEPI used cells and laboratory animals to evaluate the health risk of the magnetic field generated by IH cookers (IH magnetic field) through conducting an exposure experiment, then conducted various evaluation tests relating to health risks, such as the reproductive and developmental toxicity, and clarified that the IH magnetic field had no adverse effects. Furthermore, CRIEPI is continuing efforts to elucidate the carcinogenicity of IH magnetic fields, which is not as yet fully investigated.

Intermediate Frequency
The frequency band between the low frequency band (300 Hz or less) and high frequency band (10 MHz or more).

Outline of Results

◇ Exposure experiments of an intense magnetic field at the heating frequency of an IH magnetic field

In order to investigate the carcinogenicity of IH magnetic fields, we used 50 each of male and female genetically modified mice susceptible to carcinogens. Each sex of these mice was equally divided into 2 groups: control and magnetic field-exposed groups. The control group would not be exposed to a magnetic field, while the exposed group mice were exposed to a magnetic field at the heating frequency of an IH cooker (20 kHz) that was generated by CRIEPI's magnetic field exposure facility for animals, the world largest of its kind. The magnetic field intensity for our experiment was set at 200 μT, one order of magnitude higher than the 27 μT stipulated in international exposure guidelines. The exposure period was made six months, which is the period of time that cancer begins to occur spontaneously and complies with international test guidelines on safety evaluation using this strain of mice. As a result of histopathological evaluations of neoplastic lesions in the organs and tissue of the mice after the experiment, there was no statistically significant increase in the frequency of neoplastic lesions in each organ and tissue of the exposed mice compared with those of the control group of mice. Obtained results demonstrated that, under the conditions used for this experiment, exposure to the magnetic field was not carcinogenic in this mouse model (Table 1).

◇ Confirming reproducibility of results through a rigorous experimentation method complying with international testing guidelines

CRIEPI conducted a series of animal/cell experiments complying with international testing guidelines applied to safety evaluations for pharmaceutical products, etc. Furthermore, for our animal experiments, we collaborated with accreditation bodies adhering to the Good Laboratory Practice and performing histopathological examinations under blinded magnetic field exposure conditions, thus securing reliability of the results. We also verified the reproducibility of results by duplicating the same experiment.

Blind Test
A method of ensuring the objectivity of data analysis by masking the exposure conditions from the person analyzing the data.

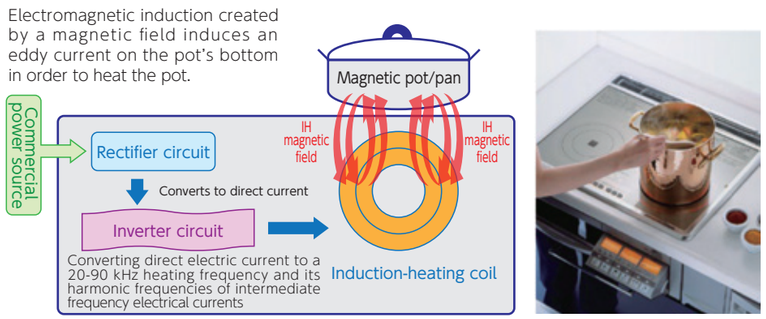
Table 1 Main 4 toxicity tests directly connected to health risk evaluation and the results thereof

Evaluation item (laboratory animal, etc.: biological endpoints)	Test result
Reproductive and developmental toxicity Preimplantation period (rats: infertility, miscarriage) Organogenesis (rats: malformed and underweight fetuses)	No effect
Toxicity Acute toxicity (rats: body weight, hematological changes) Sub-chronic toxicity (rats: histopathological changes)	No effect
Genotoxicity Mutagenicity, chromosomal abnormality (cells, microorganisms)	No effect
Carcinogenesis (this research) Tumorigenesis (genetically-modified mice, neoplastic lesions)	No effect

Through CRIEPI's research, numerous highly-reliable test results have been produced regarding important health risk indicators.

Izumi Nishimura
Biological Environment Sector, Environmental Science Research Laboratory

Laboratory animals magnetic field exposure facility
A unit that exposes mice and other laboratory animals to high-intensity IH magnetic fields for a prolonged period of time to evaluate the biological effects of the magnetic fields.



Mechanism of an intermediate frequency magnetic field (IH magnetic field) being generated from an IH cooker

Application Examples of Research Results

The results obtained through CRIEPI's research and others will be compiled in health risk evaluation documents, such as the Environmental Health Criteria published by the World Health Organization, through public disclosure in international scientific journals, then reflected in the exposure standards and regulatory values of each country. Within Japan, these research results have been disclosed via the website of the Japan EMF Information Center, an organization which disseminates fair and neutral information, and is helping improve understanding regarding the health risks of the magnetic fields associated with IH cookers and wireless power transfer systems for electric vehicles.

References: Nishimura et al., J. Appl. Toxicol., Vol. 36, p. 199 (2016)

Environment

Development of a General-Purpose 3D Numerical Model for Thermal Discharge Diffusion and Cooling Water Intake

Contributing to realizing efficient environmental assessments through provision of a swift dispersion prediction technique.

Background

Environmental Assessment
A process of investigating, predicting and assessing likely environmental impacts of large-scale development projects, etc. in advance.

When performing environmental assessments for the new construction or replacement (rebuilding) of power plants, there is a need to evaluate the impact of discharge of warm water used for cooling purposes in nuclear power plants, thermal power plants, etc. on the coastal ocean. Depending on the circumstances, either a hydraulic model experiment or numerical simulation is used as the technique to predict diffusion of warm water discharge, however due to the increased complexity of power plant location conditions in recent years, there is a need for evaluations that also consider the impact of adjacent existing power plants and river waters, simultaneously. Moreover, there is a desire to further speed up the prediction and evaluation process in order to reduce both the time and cost for environmental assessments. CRIEPI is engaging in the development of a general-purpose 3D numerical model applicable to both thermal discharge diffusion prediction and recirculation evaluation that does not depend on the differences in cooling water intake methods, location conditions, etc.

Outline of Results

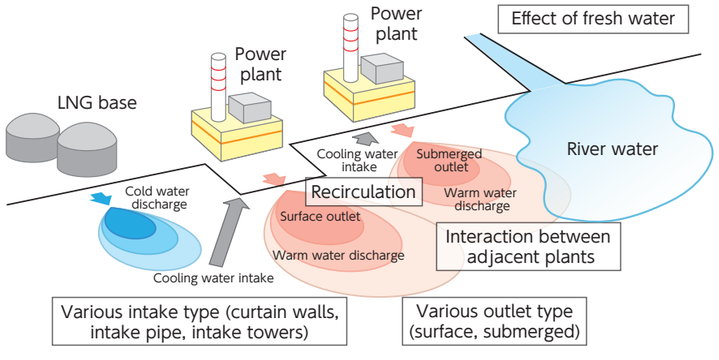
◇ Development of the 3D model capable of predicting the diffusion of thermal (warm/cold) water discharge under various conditions

Curtain Wall
A wall built on the front of a water intake inlet so as to take in low-temperature bottom seawater and shut out warm water close to the surface.

CRIEPI developed the 3D model that response to the various water intake methods, such as intake towers and curtain walls, as well as both the surface and submerged discharge methods. By using this model, it is also possible to make predictions regarding the impact of the adjacent power plant (cumulative) and recirculation (mixing into intake water) of warm water discharge, which was not possible using the conventional surface 2D model. Moreover, because this model can predict not only the diffusion of warm water discharge but also that for cold water discharge, it can also be used for environmental assessments of LNG bases with cold water discharge.

◇ Provision of a swift prediction technique as a substitute to model experiment

CRIEPI confirmed that the warm water discharge diffusion prediction results obtained using the 3D model had equivalent accuracy to results obtained using the conventional hydraulic model experiment. This means it is possible to swiftly predict the diffusion in locations with complicated geological features, which previously required a combination of the hydraulic model experiment and numerical simulation. This technique can also be utilized when studying specifications of water intake equipment in the design stage, which previously relied on model experimentation.



Prediction target of the general-purpose 3D model

Norikazu Nakashiki
River and Coastal Environment Sector,
Environmental Science Research Laboratory

High performance parallel computer Utilized in calculations based on the 3D thermal discharge diffusion model.

Comparison of the general-purpose 3D model, conventional surface 2D model and Hydraulic model experiment
(○: applicable ×: not applicable)

Prediction target	General-purpose 3D model	Surface 2D model	Hydraulic model experiment
Warm water discharge (surface drainage)	○	○	×
Warm water discharge (submerged drainage)	○	×	○
Recirculation	○	×	○
Cold water discharge	○	×	○
Impact of adjacent power plant	○	×	×

Application Examples of Research Results

As a technique substituting the hydraulic model experiment, the 3D model can be applied to locations where prediction using numerical simulation had proven difficult to date, thus contributing to a reduction in the time and cost required for environment assessments, equipment design, etc.

References: Tsubono et al., Journal of Japan Society of Civil Engineers B1 (Hydraulic Engineering) Vol. 74, I_775 (2018)
Niida et al., Journal of Japan Society of Civil Engineers B1 (Hydraulic Engineering) Vol. 73, I_583 (2017)

2–2. Major Research Results -20

Utility Management

Quantitative Analysis of the Role of Nuclear Power in Energy Policy in Japan

Fostering concrete understanding of the importance of nuclear power on Japan's macro economy

Background

The Long-term Energy Supply and Demand Outlook, published by the Ministry of Economy, Trade and Industry in July 2015, has established a target of nuclear power ratio between 20 to 22% of the overall power generation mix in 2030. While proper maintenance and utilization of the nuclear power stock is indispensable to achieve this goal, it might turn out difficult to deliver due to, for instance, delay in recommencement of nuclear power plant units. CRIEPI has assessed the impact if nuclear power generation does not reach the target ratio in Japan's power mix.

Long-term Energy Supply and Demand Outlook
The document stating the outlook for future energy supply and demand configuration based upon the policies stated in the Strategic Energy Plan.

Outline of Results

◇ Analysis of impact on GDP and industry

With its own macro-economic simulation model, CRIEPI analyzed the future economic situations based on the assumption that the 2030 nuclear power generation ratio was 15%, 7% below the published target, which was compensated either by LNG-fired power and by renewable energy. Through this analysis, we calculated that the real GDP in the year 2030 would decrease by approximately 2.5 trillion yen if the remaining 7% was compensated by LNG-fired power, or by approximately 2.7 trillion yen if compensated by renewable energy (Fig. 1). Moreover, we also calculated that the cumulative decrease in total industrial investment in real term by 2030, which, if LNG-fired power was to compensate nuclear power, would be 2.3 trillion yen, of which 1.7 trillion yen decrease is attributed to the manufacturing sector specifically. Alternatively, if renewable energy was to compensate nuclear power, the decrease would be 2.5 trillion yen for the whole industry, of which 1.9 trillion yen decrease for the manufacturing sector (Fig. 2).

Total Industrial Investment in Real Term
Amount of investment adjusted with price increases/decreases.

◇ Analysis of impact on household incomes

As for the per capita GDP, which is a proxy indicator for income, CRIEPI simulated that, in 2030, the per capita GDP would decrease by approximately 21,000 yen and 23,000 yen if the 7% of total power mix was compensated for by LNG-fired power and renewable energy, respectively.

Proxy Indicator
An indicator used as a substitute if the target indicator is difficult to directly measure.

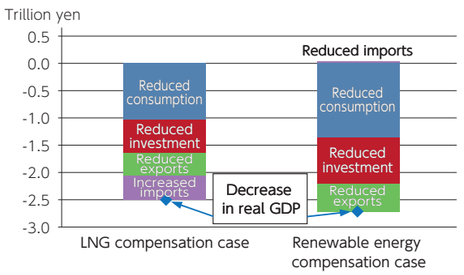


Fig. 1 Decrease in real GDP and the breakdown thereof assuming the target ratio for nuclear power is not reached (for the year 2030)

Factors of a decrease in GDP are as follows: (1) increased imports in line with an increase in fossil fuel imports, (2) decreased consumption due to a decrease in real income in line with increased prices, (3) decreased exports and decreased investment in line with weakened international competitiveness due to an increase in prices.

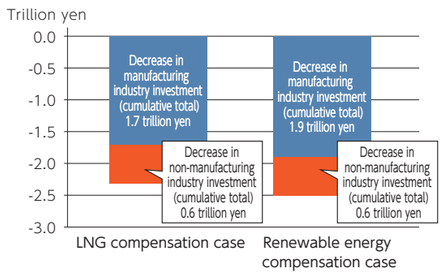
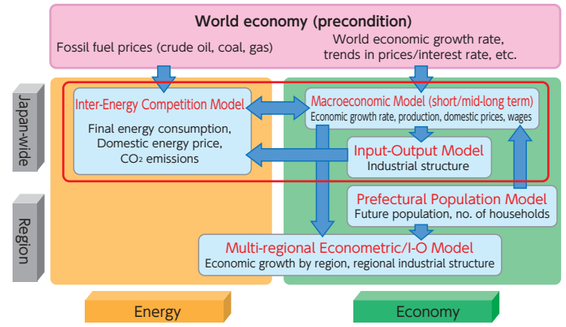


Fig. 2 Cumulative decrease in real investment and the breakdown thereof assuming the target ratio for nuclear power is not reached (for the year 2030)

Disseminates quantitatively analyzed results regarding the roles of energy and environmental policies in Japan's economy.

Structure of CRIEPI's model system

By exchanging common variables between the Inter-Energy Competition Model (left) and the Macroeconomic Model/Input-Output Model (right), it is possible to obtain simulation results consistent among the economy, industrial structure and energy each other. One characteristic of this system is that the economic impact by individual industrial sector can be shown. The red rectangle indicates the model boundary used for the calculations described above.



Application Examples of Research Results

These research results were featured in the "Proposal for Future Energy Policy" published by the Japan Business Federation in November 2017 and are also used in other media channels to help better understanding regarding the role of nuclear power generation.

References: Hamagata et al., CRIEPI Research Report Y17502 (2017)
Hamagata et al., CRIEPI Research Report Y12033 (2013)

2-2. Major Research Results-21

Common in the Multiple Fields

Development of a Tool Analyzing the Operational Characteristics of Smart Communities

Contributing to the visualization of the relationship between PV, storage batteries, demand response and power quality

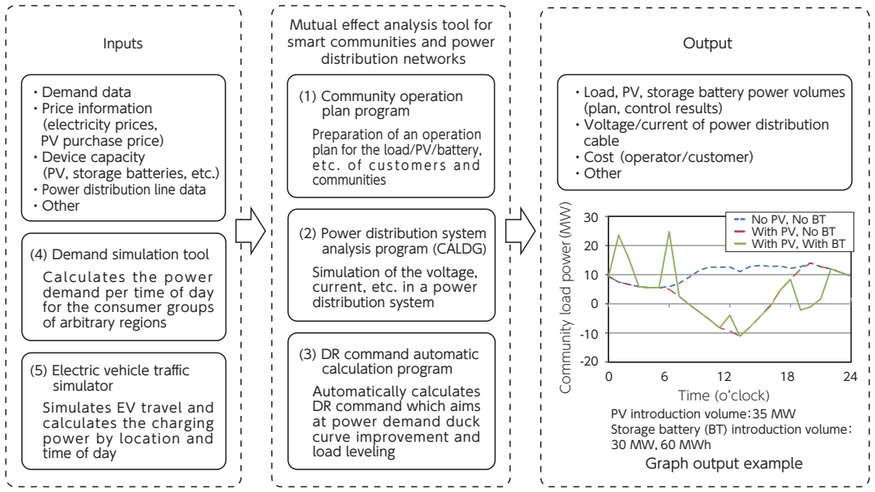
Background

The proactive involvement of the customer in efficient production and utilization of energy is essential to the realization of smart communities. Various retail operators and aggregators utilizing customer-side energy resources appear in the communities and VPP technology is used on a regular basis. If these communities adopt an autonomous operation approach that only values economic performance (cost minimization, etc.) there is a concern that, if the demand fluctuation in the power distribution system further increases, voltage fluctuation will also increase, leading to a deterioration of power quality and excessive current in power transmission/distribution lines, etc. With the aim of achieving both rationalization of power transmission/distribution system operation and facility construction, as well as the economic operation of smart communities, CRIEPI has developed a tool to analyze the mutual effect between communities and power distribution networks.

Outline of Results

◇ Development of a mutual effect analysis tool for smart communities and power distribution networks

By linking the community operation plan program (1) and power distribution system analysis program (2) already developed by CRIEPI, we established a tool to analyze mutual effect. This tool makes it easy to analyze the impact that community autonomous operation has on the power quality of power distribution systems and, in the reverse, the impact that limitations relating to power quality of power distribution systems has on community operational characteristics. This tool has a function to simulate demand response (DR) which aims for power demand duck curve improvement, load leveling, etc. (3), and is able to analyze the impact of DR. Moreover, community demand data is necessary for analysis, therefore a function utilized in the analysis of power demand data in arbitrary regions prepared with CRIEPI's existing demand simulation tool (4) and electric vehicle traffic simulator (5) was added to create a highly-practical tool.



Overview of the mutual effect analysis tool for smart communities and power distribution networks Inputs

Smart Community

A social system based on a next-generation power transmission/distribution network (smart grid) within a fixed community scale which controls customer-side energy resources (renewable energy, co-generation, storage battery, demand response, etc.) through an energy management system utilizing ICT and IoT to achieve total management of energy utilization in a region as well as provide a new social service.

Aggregator

A broker who cooperates with the efficient operation of energy management through bundling the power demand of multiple customers and customer-side energy resources to establish a certain scale of demand and/or supply capability.

VPP

A mechanism to make the customer-side energy resources dispersed across various regions function as if one power plant. Contributes to the balancing of power supply/demand as if a large-scale power plant.

Duck Curve

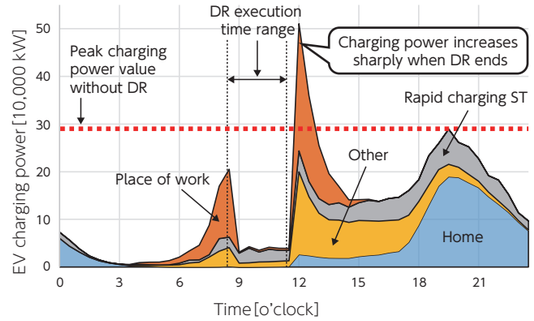
Describes the trend whereby real power demand (net power demand obtained after subtracting photovoltaic power volume from the actual power demand) drops largely during the daytime and increases in the evening. The name "duck curve" comes from the fact that the power demand curve over the course of one day is shaped like a duck (the stomach during the day, head during the evening).

Eitaro Omine / Hiroyuki Hatta
Distribution System Unit, Energy Innovation Center

Supporting the practical operations of power transmission/distribution companies and community operators with a tool to analyze the operational characteristics of smart communities.

Example of an analysis using the developed tool

This is an example of analyzing a case whereby the DR command suppressing charging of an electric vehicle (EV) is executed at 9:00 and ended at 12:00. This example assumes that the all EVs can be connected to chargers when parked at the owner's place of work, home, etc. Charging power drops once from 9:00 onwards but then increases sharply when DR ends at 12:00 and exceeded the peak value without DR signal.



Application Examples of Research Results

The results of this research are contributing to the appropriation of facility formation in power distribution systems including smart communities, such as the judgment regarding locations for installing voltage control equipment and streamlining of equipment carried out by power transmission/distribution companies. The results of this research are also contributing to the optimization of the operation plans prepared by community operators as well as cost-reduction and rationalization of voltage/current management tasks conducted by power transmission/distribution companies when operating power distribution systems.

References: Hatta et al., CRIEPI Research Report C17010 (2018)

Development of an Evaluation Technology to Achieve Long-Life Lithium-ion Batteries

Common in the Multiple Fields

Contributing to the long-term operation of rechargeable batteries suited to the stationary application through performance evaluations

Background

Renewable energies, such as photovoltaic and wind power generations, are being introduced against global warming. To connect them to power grid systems, the destabilizing effect on the systems is of concern. Lithium-ion batteries (LiBs) are as one of procedures to achieve the stable system. Moreover, in the transportation sector, the increase of electric vehicles (EV) is determined as one of the measures to achieve a low-carbon society, therefore it is predicted that the demand for rechargeable batteries will continue to rise. CRIEPI continues R&D of an all-solid-state battery which can be used as stationary storage and also for EVs. We are also developing an evaluation technology to achieve long-life lithium-ion batteries.

Lithium-ion Battery (LiB)

A rechargeable battery that charges and discharges by transferring lithium ions between the positive and negative electrodes. Various materials are used to make the electrodes, however in many cases, carbon (graphite) is used for the negative electrode and lithium cobalt oxide is used for the positive electrode. The separator is sandwiched between positive electrode and negative electrode sheet, and multi-layers are piled up and the entire battery is then soaked in an organic electrolyte solvent.

Outline of Results

◇ Development of an all-solid-state battery with further safety

Currently used LiBs have a risk of fire incidents due to a flammable organic solvent used inside them. In order to safely operate the large-scale power storage systems expected in the future, CRIEPI is developing an all-solid-state battery made from fire-retardant materials. Through the optimized design of a solid polymer electrolyte combined with the positive/negative electrode material of existing LiBs, we succeeded in developing a longer life battery than existing LiBs. Furthermore, we started to develop a new battery consisting of only inorganic materials to improve safety performance (nonflammability, etc.).

◇ Analysis and evaluation of various LiBs based on electrode material characteristics

LiBs started to be installed for stationary use. CRIEPI clarified the respective elemental components and crystalline structures of the positive and negative electrodes in LiBs, and conducted a charging/discharging experiment on half-cells (positive or negative electrode individually) to elucidate the relationship between the electrode material and charge/discharge characteristics. Based on this result, we developed a technique to estimate the life characteristic of LiBs with various combinations of positive and negative electrodes (Fig. 1).

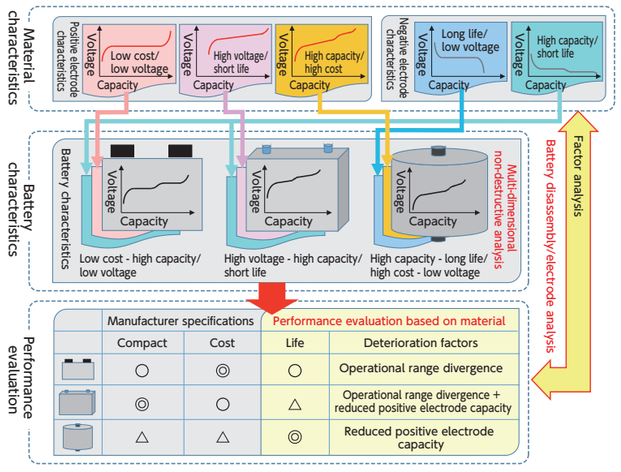
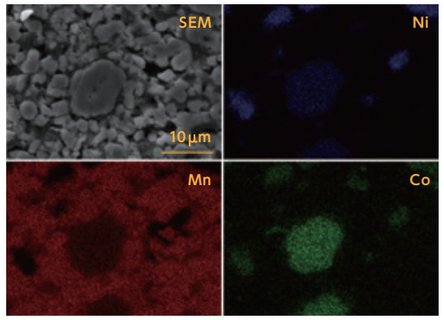


Fig. 1 Scheme of battery deterioration characteristics through combinations of various electrode materials

Yo Kobayashi
Electrochemical Sector,
Materials Science Research Laboratory

Promotes development of next-generation rechargeable batteries and engages in activities aimed at improving evaluation technology of LiB material deterioration factors, battery life estimates, etc.



Analysis example of the positive electrode surface in the LiB by electron microscopy

Application Examples of Research Results

By using the various LiB evaluation technologies, it is possible to select the suitable LiB for the stationary application and select the right battery to suit running conditions and operations. Moreover, CRIEPI will push ahead with the development of a safer next-generation battery with the aim of realizing a large-scale storage battery for stationary use responding to future expansion of renewable energy.

References: Kobayashi et al., CRIEPI Research Report Q16001 (2017)
Yamazaki et al., CRIEPI Research Report Q16010 (2017)
Kobayashi et al., J. Power Sources, Vol. 341, p. 257 (2017)

Compared with the previous fiscal year, ordinary income fell by approximately 900 million yen due primarily to decreased business revenue relating to consigned research, however ordinary expenses also fell approximately 200 million yen due primarily to a reduction in expenses such as consumable goods expenses, therefore although there was a reduction in the change in ordinary profit, a surplus of approximately 400 million yen was achieved.

Net Assets Variation Statement

(Unit: 1 mill yen)

Change in general net assets

	FY2017	FY2016	Difference		FY2017	FY2016	Difference
Ordinary expenses	29,576	29,803	△226	Ordinary revenue	30,010	30,956	△945
Labor costs	9,909	9,735	174	Ordinary benefit received	25,385	25,249	136
General running costs	19,667	20,068	△400	Operating revenue	4,204	5,415	△1,211
				Other revenue	233	103	130
				Transfer from designated net assets	186	188	△1
Current ordinary profit	433	1,153	△719				
Current general net assets change	3,640	2,842	798				

Change in designated net assets

	FY2017	FY2016	Difference		FY2017	FY2016	Difference
Transfer to general net assets	186	188	△1	Subsidy etc. received	108	78	29
Current designated net assets change	△78	△109	30				
Current net assets change	3,561	2,732	829				

Balance Sheet

(Unit: 1 mill yen)

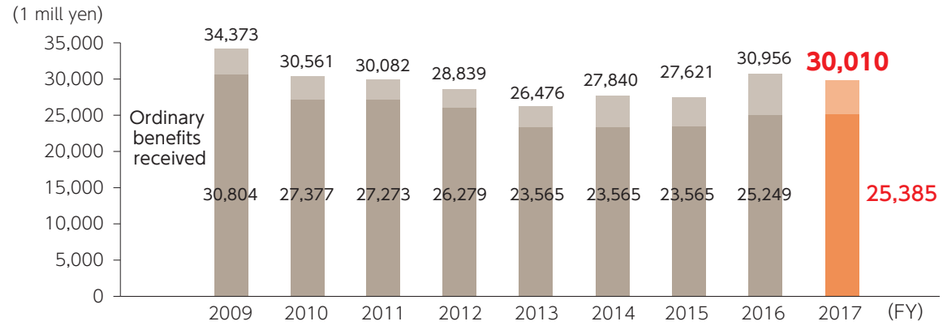
Assets

	FY2017	FY2016	Difference
Current assets	5,659	4,546	1,113
Fixed assets	53,326	49,726	3,600
Total assets	58,986	54,272	4,713

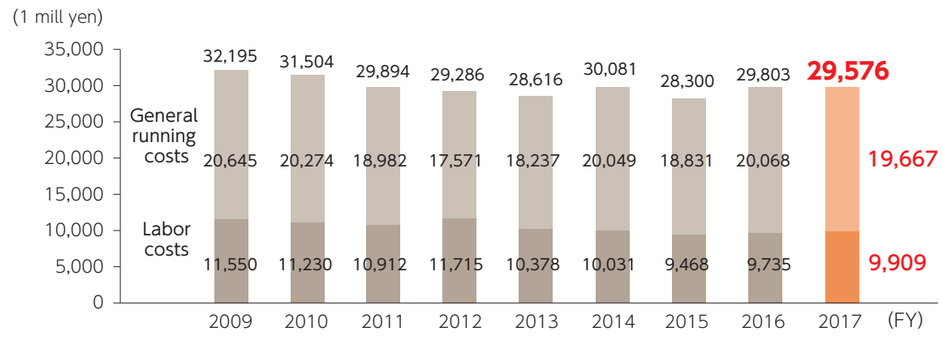
Liabilities

	FY2017	FY2016	Difference
Current liabilities	5,238	4,274	964
Fixed liabilities	9,357	9,170	187
Total liabilities	14,595	13,444	1,151
Net assets			
Designated net assets	324	403	△78
General net assets	44,066	40,425	3,640
Total net assets	44,390	40,828	3,561

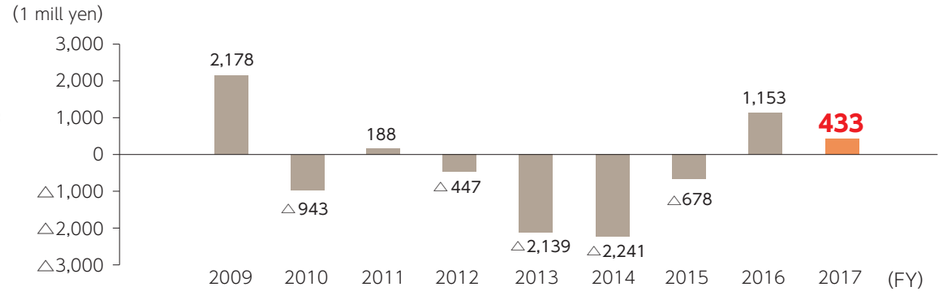
Transition of ordinary revenue※



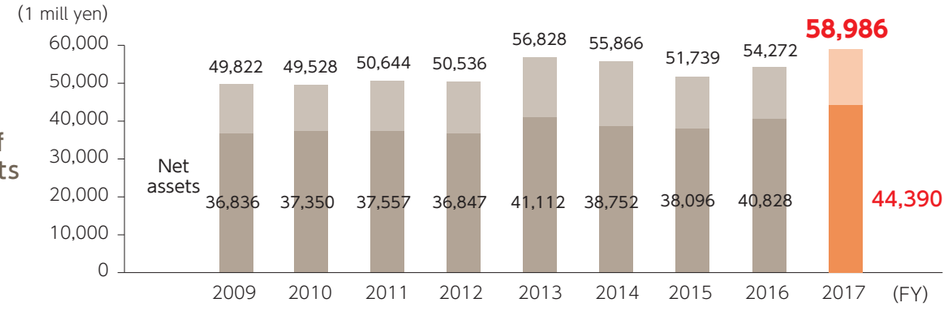
Transition of ordinary expenses※



Transition of ordinary profit※



Transition of overall assets



* From FY2016, loss on retirement of fixed assets is included in ordinary expenses, therefore figures for the previous financial year have been rearranged accordingly.

2. Financial Statement

Balance Sheet

As of March 31, 2018

(Unit: 1,000yen)

Account	Current fiscal year	Previous fiscal year	Change
Ⅰ Assets			
1. Current assets			
Cash and deposit	2,767,594	1,630,185	1,137,409
Accounts receivable	2,819,506	2,770,263	49,243
Suspense payments	9,190	130,400	△ 121,209
Advance payments	63,608	15,911	47,697
Total current assets	5,659,900	4,546,760	1,113,140
2. Fixed assets			
(1) Special assets			
Buildings	147,955	164,985	△ 17,029
Facilities attached to buildings	0	0	-
Structures	870	1,045	△ 174
Machine and equipment	163,015	234,063	△ 71,047
Tools and furniture	36,532	43,822	△ 7,289
Lump-sum depreciable assets	1,843	2,805	△ 961
Intangible fixed assets	6,498	9,317	△ 2,819
Special assets for retirement lump sum grants benefits package allowance	3,435,900	3,435,900	-
Specific assets for depreciation allowance	4,400,000	2,800,000	1,600,000
Special assets for acquisition of research facilities reserves	-	2,192,500	△ 2,192,500
Special assets for special project reserves	510,000	510,000	-
Specific assets for base establishment allowance	5,687,233	2,695,127	2,992,106
Total special assets	14,389,850	12,089,566	2,300,283
(2) Other fixed assets			
Land	9,110,323	9,137,685	△ 27,361
Buildings	12,885,997	11,988,630	897,366
Facilities attached to buildings	6,055,570	4,482,670	1,572,900
Structures	1,971,809	1,476,562	495,246
Machine and equipment	6,206,504	6,571,926	△ 365,421
Tools and furniture	1,776,312	1,600,935	175,377
Rolling stock and vehicles	24,261	23,680	580
Lump-sum depreciable assets	95,717	79,122	16,595
Intangible fixed assets	698,219	695,241	2,978
Construction in progress accounts	112,029	1,580,180	△ 1,468,151
Total other fixed assets	38,936,746	37,636,636	1,300,110
Total fixed assets	53,326,596	49,726,202	3,600,394
Total assets	58,986,497	54,272,963	4,713,534
Ⅱ Liabilities			
1. Current liabilities			
Accounts payable	4,889,122	3,519,784	1,369,338
Deposits received	89,178	86,607	2,570
Advances received	5,252	407,614	△ 402,362
Accrued bonus	255,000	260,000	△ 5,000
Total current liabilities	5,238,553	4,274,006	964,546
2. Fixed liabilities			
Allowance for retirement benefits for directors	383,000	435,000	△ 52,000
Accrued retirement benefits for employees	8,974,000	8,735,000	239,000
Total fixed liabilities	9,357,000	9,170,000	187,000
Total liabilities	14,595,553	13,444,006	1,151,546
Ⅲ Net assets			
1. Designated net assets			
Special benefits	209,047	261,776	△ 52,728
Subsidies	38,162	67,841	△ 29,679
Donations, etc.	77,483	74,024	3,459
Total designated net assets	324,693	403,642	△ 78,948
(including appropriation to special assets)	(324,693)	(403,642)	(△ 78,948)
2. General net assets	44,066,250	40,425,314	3,640,936
(including appropriation to special assets)	(10,629,256)	(8,250,023)	(2,379,232)
Total net assets	44,390,944	40,828,956	3,561,987
Total of liabilities and net assets	58,986,497	54,272,963	4,713,534

Statement of Changes in Net Assets

From April 1, 2017 to March 31, 2018

(Unit: 1,000yen)

Account	Current fiscal year	Previous fiscal year	Change
Ⅰ General net assets change			
1.Ordinary profit			
(1)Ordinary revenue			
[1] Benefit received			
Ordinary benefit received	25,385,390	25,249,026	136,364
[2] Operating revenue	(4,204,282)	(5,415,715)	(△ 1,211,432)
Consigned research operating revenue	3,764,738	4,952,427	△ 1,187,689
Other operating revenue	439,544	463,287	△ 23,742
[3] Other revenue	233,964	103,580	130,384
[4] Transfer from designated net assets	186,976	188,272	△ 1,296
Total ordinary revenue	30,010,613	30,956,593	△ 945,980
(2)Ordinary expenses			
[1] Operating expenses			
Labor	(8,926,988)	(8,807,813)	(119,174)
Salary and benefit	6,797,290	6,724,773	72,516
Retirement benefit	1,131,621	1,083,562	48,058
Welfare	998,077	999,478	△ 1,400
General expenses	(18,962,130)	(19,359,482)	(△ 397,351)
Supplies and printed materials	2,138,632	3,373,500	△ 1,234,867
Utilities	796,875	722,813	74,061
Outsourcing costs	6,658,044	6,110,377	547,667
Joint research contribution	294,923	288,292	6,630
Repair expenses	1,751,142	1,502,004	249,138
Rent	340,307	300,050	40,257
Taxes and dues	555,049	578,216	△ 23,166
Travel and transport	844,834	728,498	116,336
Depreciation	4,724,267	4,824,098	△ 99,831
Loss on retirement of fixed assets	86,984	116,078	△ 29,093
Other	771,069	815,552	△ 44,483
Subtotal of operating expenses	27,889,119	28,167,296	△ 278,176
[2] Administrative expenses			
Labor	(982,349)	(927,387)	(54,962)
Director remuneration	142,480	141,110	1,370
Salary and benefits	619,347	576,722	42,624
Retirement benefit	81,263	76,568	4,694
Welfare	78,738	75,945	2,792
Transfer of allowance for director retirement benefits	60,520	57,040	3,480
General expenses	(705,479)	(708,824)	(△ 3,344)
Supplies and printed materials	45,179	50,609	△ 5,430
Utilities	5,684	5,650	33
Outsourcing costs	131,527	117,169	14,357
Repair expenses	15,989	17,104	△ 1,115
Rent	339,425	338,839	585
Taxes and dues	46,629	45,915	713
Travel and transport	22,241	20,171	2,070
Depreciation	15,092	26,327	△ 11,235
Loss on retirement of fixed assets	117	110	6
Other	83,594	86,925	△ 3,331
Subtotal of administrative expenses	1,687,829	1,636,211	51,617
Total Ordinary expenses	29,576,948	29,803,508	△ 226,559
Current ordinary profit	433,664	1,153,085	△ 719,421
2.Non-recurring change			
(1)Non-recurring profit			
[1] Gain on sale of fixed assets	3,192,519	2,441,665	750,854
[2] Gain on donation of fixed assets	14,752	12,525	2,227
Total non-recurring profit	3,207,272	2,454,190	753,081
(2)Non-recurring expenses			
[1] Business structural reform cost	-	266,382	△ 266,382
[2] Fixed asset impairment loss	-	498,690	△ 498,690
Total non-recurring expenses	-	765,072	△ 765,072
Current non-recurring change	3,207,272	1,689,118	1,518,153
Current general net assets change	3,640,936	2,842,204	798,732
General net assets beginning balance	40,425,314	37,583,109	2,842,204
General net assets final balance	44,066,250	40,425,314	3,640,936
Ⅱ Designated net assets change			
[1] Subsidies received	57,671	38,674	18,997
[2] Gain on donation of fixed assets	50,356	39,754	10,601
[3] Transfer to general net assets	186,976	188,272	△ 1,296
Current designated net assets change	△ 78,948	△ 109,843	30,895
Designated net assets beginning balance	403,642	513,486	△ 109,843
Designated net assets final balance	324,693	403,642	△ 78,948
Ⅲ Net assets final balance	44,390,944	40,828,956	3,561,987

Facts & Figures

Research Reports / Research Papers / Intellectual Property

This section introduces key data on CRIEPI's FY2017 activities, including the number of report publications, number of paper presentations and number of patent applications.

Fig. 1 Transition in number of reports published

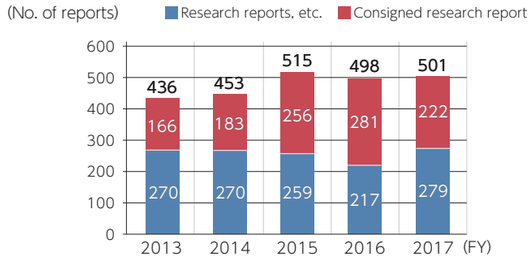


Fig. 2 Breakdown of no. of FY2017 reports by subject field

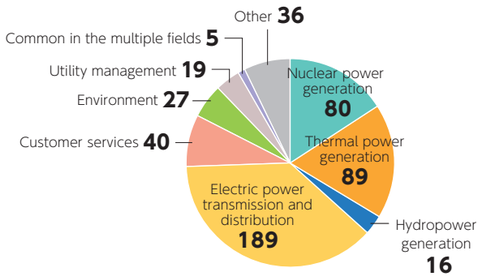


Fig. 3 Transition in no. of papers presented

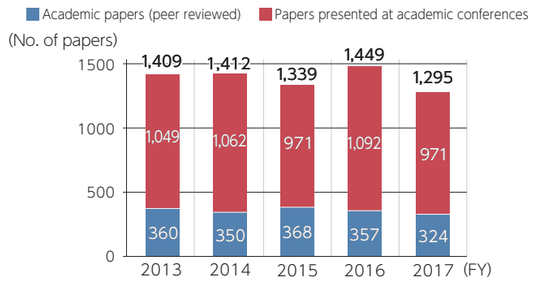


Fig. 4 Breakdown of no. of FY2017 papers by subject field

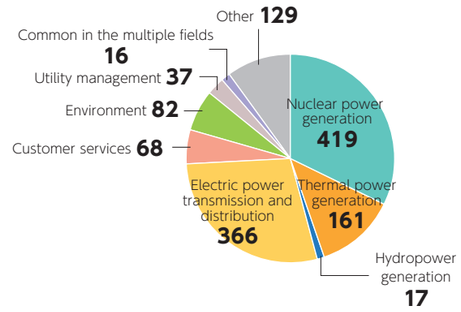


Fig. 5 Breakdown of no. of FY2017 patent applications by subject field

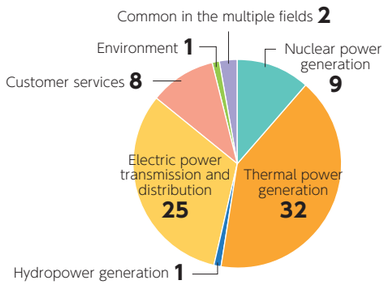
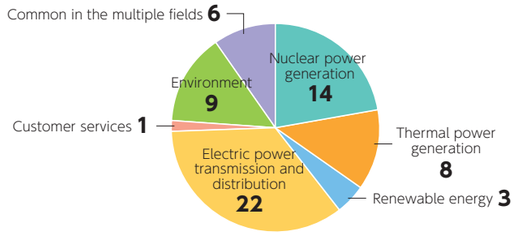


Fig. 6 Breakdown of no. of FY2017 patent registrations by subject field

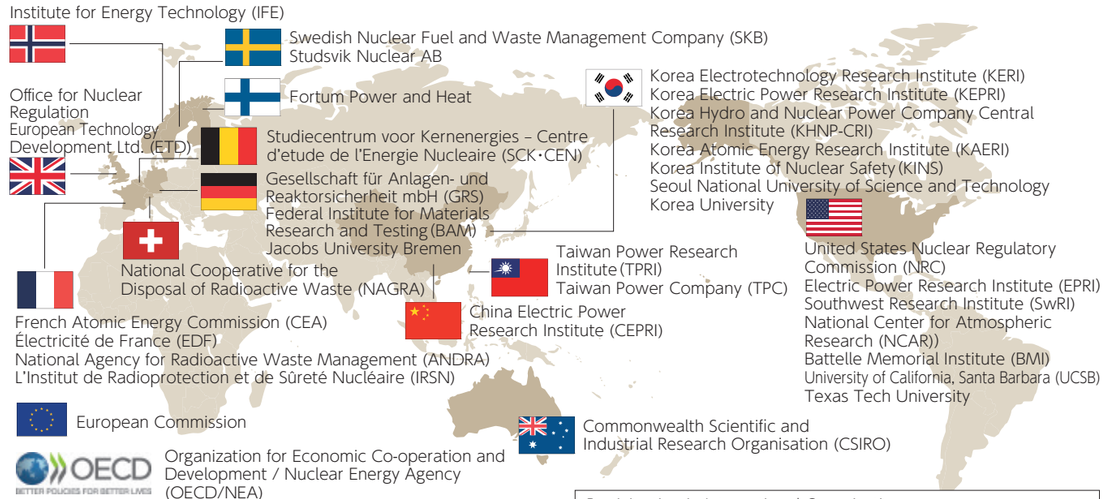


Research Network

With the aims of identifying trends in forefront energy-related R&D as well as strengthening and enhancing research networks, CRIEPI proactively promotes research cooperation agreements and engages in joint research with international partners possessing high technical standards.

In recent years, CRIEPI has been strengthening its collaborative relationships with Électricité de France (EDF) and the Electric Power Research Institute (EPRI) in particular. In November 2017, through an annual meeting with EDF, we commenced a new research collaboration related to seismic motion. CRIEPI has made other efforts to further deepen its interaction with both EDF and EPRI, such as participating in a workshop hosted by EPRI in December aimed at building an international cooperative framework for the reduction of uncertainties relating to the effects of low-dose-rate radiation.

Main Partners for Research Cooperation Agreements and Joint Research



Participation in International Organizations
Union of the Electricity Industry (EURELECTRIC)
Association of the Electricity Supply Industry of East Asia and Western Pacific (AESIEAP)
World Nuclear Association (WNA)
International Electric Research Exchange (IERE)
Electromagnetic Transients Program-Development Coordination Group (EMTP DCG) Committee

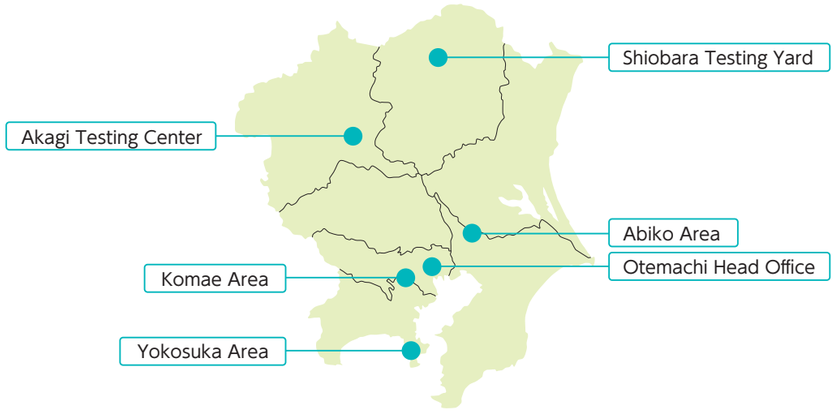
Main overseas institutions with whom CRIEPI has comprehensive cooperation agreements and the content thereof

Partner organization	Overview of partner organization	Cooperation content
Électricité de France (EDF)	France's largest electric power company founded in 1946. Conducts in-house R&D activities covering all electric power business sectors.	Cooperation agreement: Since 2012 (Main) Nuclear power generation (PRA, SA), power transmission and industry infrastructure, next-generation grid, hydrogen, customer side (Other) Nuclear power generation (maintenance/operation of power plants, life management, spent fuel management), renewable energy, power transmission infrastructure
Electric Power Research Institute (EPRI)	A nonprofit research institution established in Palo Alto, California, U.S.A. in 1973.	Cooperation agreement: Since 1976 Nuclear reactor material, low-dose-rate radiation, nuclear power risks and safety management, hydrochemistry/geothermal utilization, electric power transmission and distribution and the utilization thereof
Southwest Research Institute (SwRI)	A nonprofit research institution established in San Antonio, Texas, U.S.A. in 1947.	Cooperation agreement: Since 1997 Information exchange, personnel interaction and conducting of experiments which CRIEPI cannot conduct due to Japanese regulations, etc.

Organization

Locations

CRIEPI facilities are located in Tokyo and four surrounding prefectures in the Kanto region. These facilities consist of four research and business activities bases and two testing bases.
Currently, CRIEPI is developing its facilities with a focus on the Yokosuka Area and Abiko Area, and aims to make Yokosuka a base for research into energy and industrial technologies and Abiko a base for research into natural and environmental science.



Otemachi Area

Internal Audit Office, Head Office, Nuclear Risk Research Center, Socio-economic Research Center
1-6-1 Otemachi, Chiyoda-ku, Tokyo 100-8126　　TEL: +81-3-3201-6601

Yokosuka Area

Energy Innovation Center, Nuclear Technology Research Laboratory, Energy Engineering Research Laboratory, System Engineering Research Laboratory, Electric Power Engineering Research Laboratory, Materials Science Research Laboratory, Yokosuka Operation & Service Center
2-6-1 Nagasaka, Yokosuka-shi, Kanagawa 240-0196　　TEL: +81-46-856-2121

Abiko Area

Civil Engineering Research Laboratory, Environmental Science Research Laboratory, Abiko Operation & Service Center, Procurement Center
1646 Abiko, Abiko-shi, Chiba 270-1194　　TEL: +81-4-7182-1181

Komae Area

Komae Operation & Service Center
2-11-1 Iwadokita, Komae-shi, Tokyo 201-8511　　TEL: +81-3-3480-2111

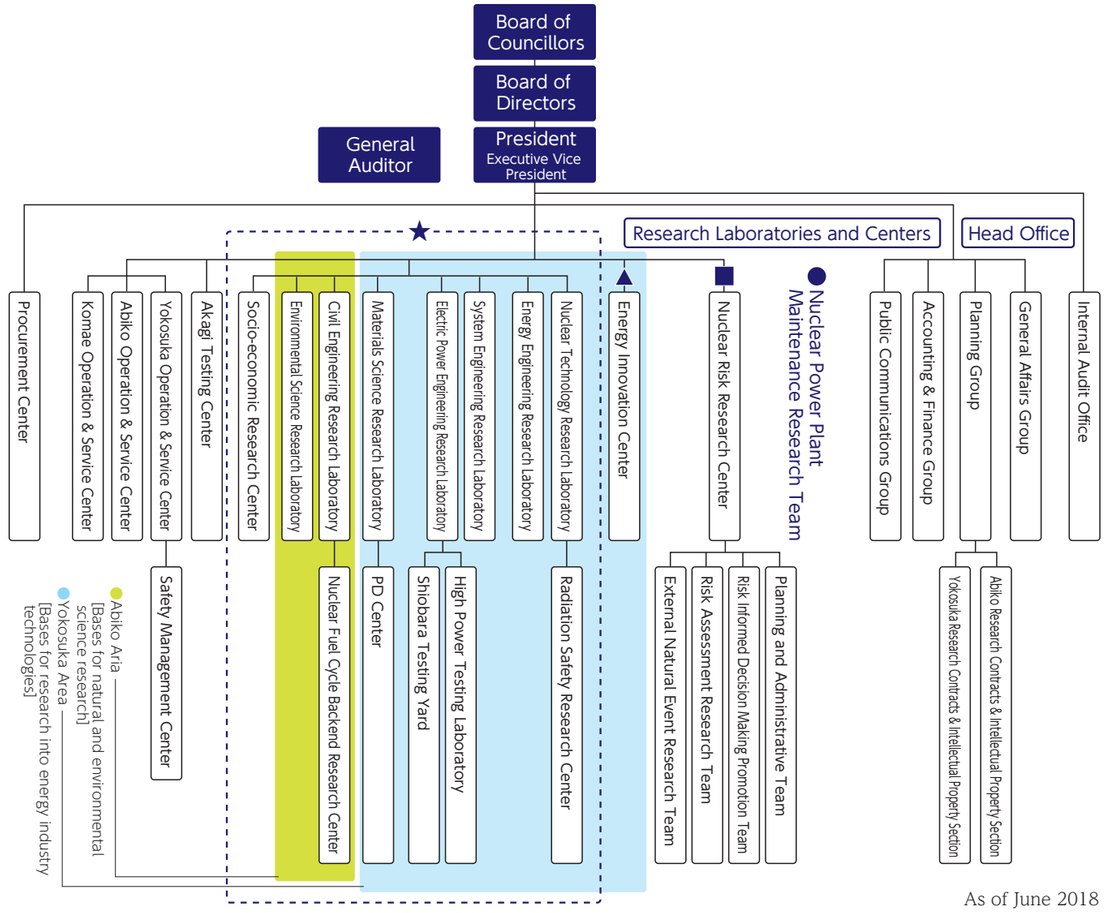
Akagi Testing Center

2567 Naegashima-machi, Maebashi-shi Gunma 371-0241　　TEL: +81-27-283-2721

Shiobara Testing Yard

1033 Sekiya, Nasushiobara-shi Tochigi 329-2801　　TEL: +81-287-35-2048

Organization



As of June 2018

★ Eight Research Laboratories

CRIEPI's research division essentially consists of eight research laboratories, each specializing in a specific subject field, with the aim of strengthening consistent research capability in each field to cover everything from basic to applied research. In addition, by forming cross-laboratory projects, CRIEPI conducts a matrix-type research framework able to respond flexibly to the needs of the electrical power industry.

■ Nuclear Risk Research Center (NRRC)

NRRC was established in October 2014 to contribute to voluntary efforts and continuous improvement of nuclear power plant safety by electric power companies. Through close liaison with business operators, the NRRC is promoting research into large-scale natural disasters and other low-frequency natural external events, probabilistic risk assessment (PRA), decision-making utilizing risk information, development of the latest risk communication techniques and other R&D aimed at risk mitigation.

▲ Energy Innovation Center (ENIC)

ENIC was established in October 2016 with the aim of comprehensively and efficiently solving issues of both the electric power sales and power distribution divisions and contributing to electric power business reform through utilization of IoT and AI. ENIC engages in research relating to advancement of electric power supply-demand management and the digital transformation of the electric power business. It also strives to achieve swift solution proposals through the Technology Promotion Unit set up within ENIC.

● Nuclear Power Plant Maintenance Research Team

This special research team leverages the combined strengths of CRIEPI's experts in a diversity of fields including nuclear power engineering, materials science and electrical engineering, to promote research in the name of securing light water reactor safety, such as countermeasures for the aging of nuclear power equipment.

Keyword Index

This Annual Report features the key words listed in 1-2. Research Reports. Explanations for each term are provided on the relevant pages.

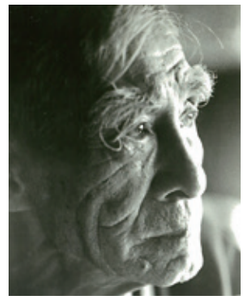


Photo by Kira Sugiyama

“Industrial research is the cultivation of wisdom, and should therefore contribute to society”

Yasuzaemon Matsunaga （1875-1971）
CRIEPI Founder, 2nd President

[About the Cover Design]

The lines of different colors and angles signify CRIEPI’s tireless efforts to create a better future ————

These lines, which are the unraveled form of CRIEPI’s first letter “C”, appear in many colors to represent the diverse subject fields of CRIEPI’s research and each of these fields converge at a single point.
That point of convergence is CRIEPI.