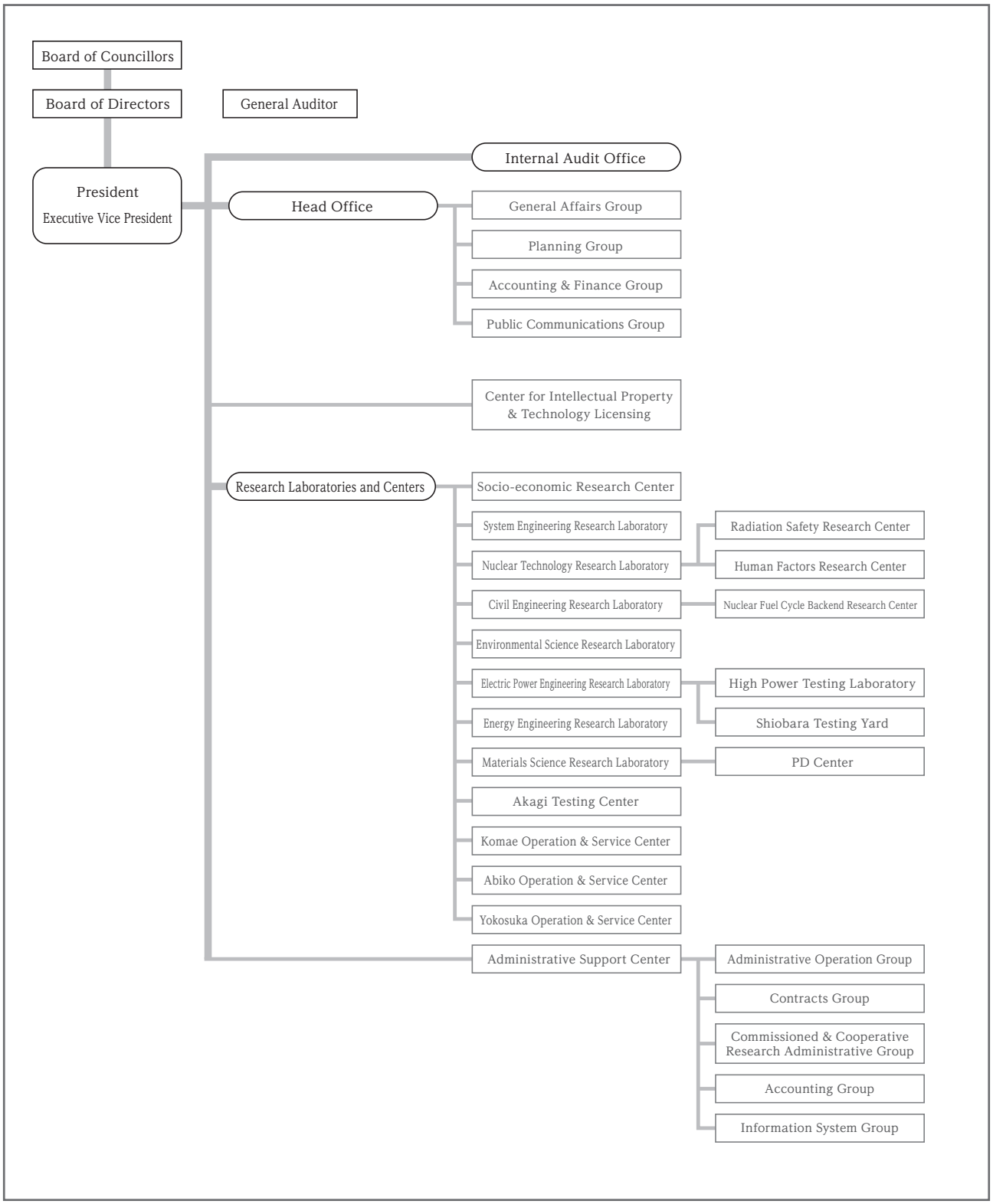
Central Research Institute of Electric Power Industry

Annual Research Report Fiscal Year 2012

CRIEPI
Central Research Institute of Electric Power Industry

Organization of the Central Research Institute of Electric Power Industry



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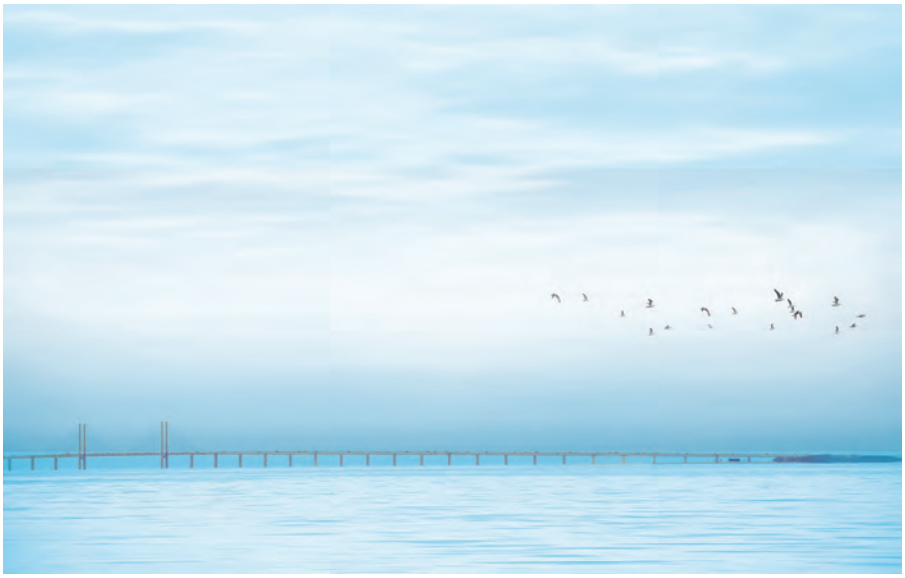

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(Pillars of research and eight research laboratories)

1. Outline of Research Activities

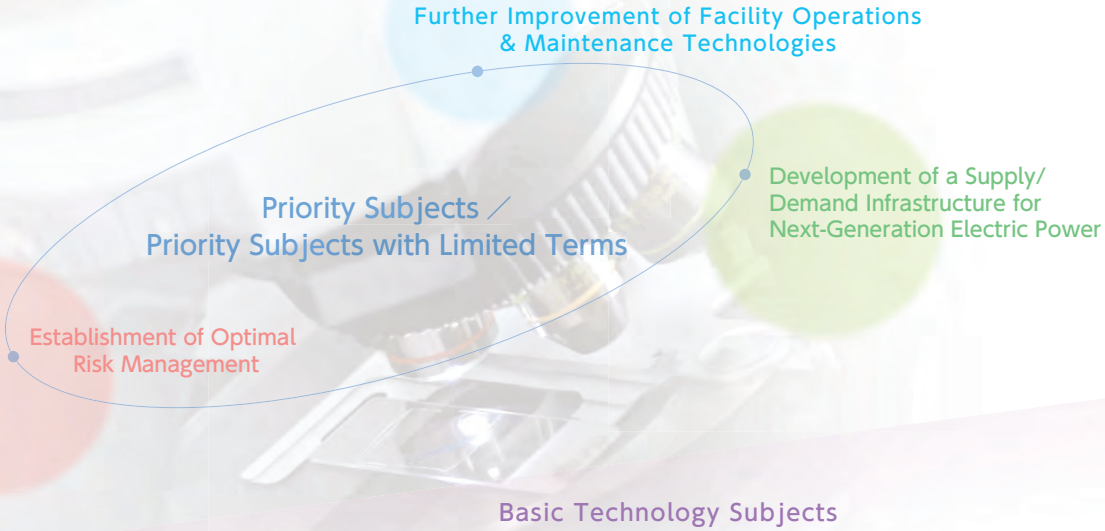
In FY 2012, CRIEPI conducted research aimed at developing a robust and flexible energy supply/demand infrastructure in order to provide a stable supply of electric power, which is the foundation of Japan's economic activity. This research was conducted under the "Three Pillars of Research", which govern our mid-term directives; namely "Establishment of Optimal Risk Management", "Further Improvement of Facility Operations and Maintenance Technologies" and "Development of a Supply/Demand Infrastructure for Next-generation Electric Power". CRIEPI also leveraged our collective strength and took priority action to address the pressing issues of nuclear power plant safety and natural disaster reduction on transmission and distribution facilities.

CRIEPI has selected 33 priority subjects to maintain and develop the technologies which are considered to be essential to current and future electric power industry. CRIEPI particularly concentrated on 9 priority subjects with limited terms, recognizing their urgency, and consequently produced solid results. 24 priority subjects and 9 priority subjects with limited terms were grouped into 11 technology categories, and research within the same area was conducted effectively. Furthermore, we launched 37 basic technology subjects and, through action leveraging the characteristics and expertise of 8 specialized research laboratories*, we strengthened our research capability by basic technological strength and areas of specialty, which is the source of solving problems faced by the electric power industry. In concrete terms, by accumulating data and know-how through field investigations and experiments and the development, maintenance and improvement of analytical techniques, basic research was conducted to conceive new ideas.

The major research results produced in FY 2012 are described in Chapter 2. The chapter lists the respective goals and results of both the priority subjects addressed by each subject and the basic technology subjects addressed by each specialized research laboratory.

To support the technology infrastructure of the electric power industry as well as maintain and strengthen CRIEPI's basic research capability, the following core research facilities were installed; several Power Conditioning System (PCS) test facilities to contribute to resolutions when large volumes of PV are introduced; a testing facility for long CV cable insulating properties to examine the insulating properties of aged CV cables; a short – wavelength laser device for atom probe devices that enables infinitesimal chemical elements to be analyzed in metal crystal grain boundaries; Electron Probe Micro Analyzer (EMPA) devices used in wide-field surface elemental analysis of radioactive materials; and an outdoors disconnect switch for use with large-capacity short-circuit testing facilities that enable a maximum of 100kA in continuous current.

*Socio-economic Research Center, System Engineering Research Laboratory, Nuclear Technology Research Laboratory, Civil Engineering Research Laboratory, Environmental Science Research Laboratory, Electric Power Engineering Research Laboratory, Energy Engineering Research Laboratory, and Materials Science Research Laboratory.



CRIEPI's R&D Portfolio in FY2012 (31st March, 2013)

Priority Subjects / Priority Subjects with Limited Terms

Priority Subjects:・ Priority Subjects with Limited Terms:○ Basic Technology Subjects:◆ Subject group: Frame enclosure
□:Society and economy □:Atomic power □:Power generation (except for atomic power)
□:Electric power circulation □: Demand side

Establishment of Optimal Risk Management

Regulations for Energy and Environment policy
○Policy toward Sustainable Structures and Regulations for Electric Utilities
・Analysis for Energy Saving and Environmental Policy – A Harmonized View of Economic Rationality and Energy Security
・Scientifically and Economically Rational Scenarios to Reduce CO_2 Emissions

Advancement in LWR safety
○Safety Assessment of LWR Systems
○Improvement of Safety Assessment Technologies on External Natural Hazards for Nuclear Facilities
○Assessment of Radioactive Material Diffusion in the Environment and its Remediation Effectiveness
・Development of Fire Modeling Methodology for Nuclear Power Plant Applications

Radiation risk elucidation
・Quantitative Evaluation of Low-Dose Radiation Risk and its Reflection on Radiation Protection

Backend Management in Nuclear Fuel Cycle
・Development and Systematization of Long-Term Safety Assessments
・Development of Long-Term Storage Management Technologies for Spent Fuel

Measures against a natural disaster of electric power distribution facilities
・Development of a Prediction Method for Meteorological and Climatic Impact on Power Facilities
・Establishment of Protective Measure Technologies against Damages of Overhead Transmission and Distribution Facilities Caused by Wind and Snow
・Development of Lightning Risk Management Schemes

Further Improvement of Facility Operations and Maintenance Technologies

LWR preservation support
・Integrity Assessment of Aged LWRs

Construction and employment / preservation support of electric generating facilities
・Development of Life Assessment Technology for High Temperature Structural Components of High Chromium Steels
・Development of Techniques for Comprehensive Impact Assessment of Thermal Power on Atmospheric Environment
・Development of Technologies for Supporting Construction and Maintenance of Power Plants from the Viewpoint of Biodiversity Conservation
・Synthesis System of Numerical Analysis for the Currents and Sediments in Rivers and Reservoirs

Employment / preservation support of electric power circulation equipment
○Demonstration of a Simplified Treatment Technique for PCB Contaminated Transformers
○Development of a Maintenance Scheme for Aged Power Transmission and Distribution Facilities
・Development of Soundness Assessment Techniques for Aged Overhead Transmission Steel Towers

Development of a Supply/Demand Infrastructure for Next-Generation Electric Power

Advancement of thermal-power-generation technology
・Improvement of Operation and Control Technologies to Diversify Fuel Types for Pulverized Coal-Fired Power Plants
・Development of Upgrading Technology for Low-Grade Energy Resources
・Development of Enhanced IGCC and Low Carbon Technologies

Next-generation Grid Technologies
○Assessment of System Security with High Penetration of Photovoltaics
・Development of a Next-Generation Coordination System for Power Demand and Supply
・Next-Generation Communications Network Systems
・Evaluation of the Feasibility of Demand Response Suitable for Japan

Electrification and Energy Conservation Technologies
○Development and Evaluation of Advanced Heat Pumps
○Development of High-Performance SiC Power Semiconductors
・Establishment of Evaluation Technologies for High Performance Secondary Batteries
・Evaluation of Energy Efficiency in Commercial Kitchens
・Acceleration of Electrification with Electric Vehicles and Secondary Battery Systems

Basic Technology Subjects

Socio-Economic Research Center
◆Utility Management and Policy
◆Economic and Social Systems
◆Energy Technology Assessment

System Engineering Research Laboratory
◆Electric Power Systems
◆Customer Systems
◆Communications Systems
◆Mathematical Informatics

Nuclear Technology Research Laboratory
◆Reactor Systems Safety Technology
◆Nuclear Fuel and Reactor Core
◆Nuclear Fuel Cycle
◆Human Factors Research

Civil Engineering Research Laboratory
◆Geosphere Science
◆Earthquake Engineering
◆Structural Engineering
◆Fluid Dynamics
◆Underground Energy Utilization Technologies

Environmental Science Research Laboratory
◆Atmospheric and Marine Environment
◆River and Coastal Environment
◆Biological Environment
◆Biotechnology
◆Environmental Chemistry

Electric Power Engineering Research Laboratory
◆High-voltage and Insulation
◆Lightning and Electromagnetic Environment
◆Applied High Energy Physics
◆Electric Power Application
◆High Current Technology

Energy Engineering Research Laboratory
◆High Efficiency Power Generation
◆Advanced Fuel Utilization
◆Heat Pump and Thermal Storage
◆Energy Conversion Engineering
◆Innovative Numerical Simulation Technology

Materials Science Research Laboratory
◆Materials for Nuclear Power Plants
◆Structural Materials
◆Materials for Energy Conversion and Storage
◆Advanced Functional Materials
◆Nondestructive Inspection
◆Materials Science Research Fundamentals

2. Major Research Results

Priority Subjects／ Priority Subjects with Limited Terms

—Establishment of Optimal Risk Management

Further Improvement of Facility Operations and Maintenance Technologies

Development of a Supply/Demand Infrastructure for Next-Generation Electric Power

Basic Technology Subjects

Priority Subjects with Limited Terms — **Establishment of Optimal Risk Management**

Policy toward Sustainable Structures and Regulations for Electric Utilities

Background and Objective

Based on discussions by the expert committee on the reform of the electric power system, the restructuring of electric utilities businesses and rate systems is looking likely. However, it is not clear whether the reforms proposed by the expert committee will bring benefits to the customers such as maintaining security of supply and optimizing the system to balance supply and demand.

In this project, we aim to identify the issues in Japan's electric power system reforms and to present socially desirable institutional framework and regulatory policy, based on case studies and quantitative analyses of the electricity restructuring in the U.S. and Europe.

Main results

1 Identifying Issues for the Security of Supply and Competition after Unbundling of the U.S. Electricity Industry

We investigated the issues in security of supply and promoting competition after unbundling in the U.S. Some regions introduced capacity market to trade the capability of supply (kW) to ensure generation adequacy. However market operation is diverse and, in general, tends to be complex (Y12020). We also investigated into a virtual divestiture as a tool for mitigating the market power of a dominant electric utility. We found the virtual divestiture has certain advantages over ownership unbundling, given that the utility is refrained from intentionally limiting the power supply from virtually divested power plants (Y12003).

2 Impact Evaluation of Liberalizations on Residential Retail Electricity Prices in the U.S. and Europe

We examined the status of retail competition after the liberalizations in the U.S. and Europe, and evaluated its impact on retail electricity prices. In the U.S., while some restructured states have experienced an increase in share of competitive suppliers and a fall in retail prices since 2008 (Fig. 2), these states faced large increases in retail electricity prices up until 2008 and only a few states lowered retail electricity prices after liberalization (Y12004). In Europe, many countries still keep regulated retail tariffs, which are too low to facilitate competition, but are difficult to abolish for political reasons (Table 1). Since residential customers do not have much interest in liberalization and do not necessarily choose the lowest price menu in the markets, it is hard to expect an immediate drop in electricity prices after liberalization (Y12017).

3 The Impacts of Renewable Energy Deployment on Electricity Markets

We surveyed the issues in promoting competition in electricity markets as well as the deployment of renewable energy sources (RES) in Europe and the U.S. We showed that, in Germany, the wholesale market clearing price could be extremely low due to the rapid penetration of RES supported by feed-in tariffs (FITs). We also found that the penetration of renewable energy causes problems such as network constraints and cost increase from frequent re-dispatching orders that reduce the output of RES (Y12009). As for the U.S., we found that in the recent legal discussions over consistency between renewable purchase obligations and the transmission independence policy, i.e., open access, it has been recognized that conflict exists between the open access policy that treats all types of generating technologies equally and the purchase obligations that only favor RES generators. In addition, we found that the establishment of transmission open access necessitates a partial abolishment of renewable purchase obligations (Y12027).

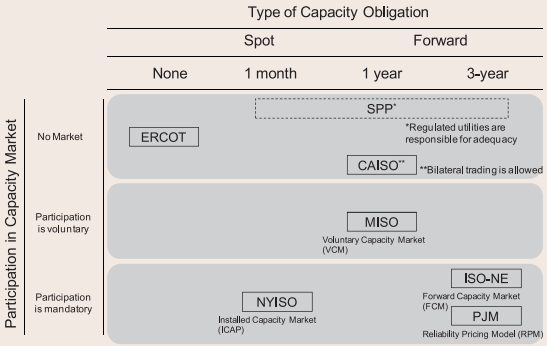


Fig. 1: Categorization of Capacity Markets in the U.S.

Capacity market designs differ in several aspects: some markets require forward capacity obligation; in one area, participation is voluntary (Midwest, MISO); and in another area, only bilateral trading is allowed (California). ERCOT's region (Texas) has no capacity obligation and rely solely on high wholesale power prices to induce generation investment, but reserve margin will be tight in the near future and creation of capacity market is debated. There are many parameters to be predetermined in order to run a capacity market, such as required reserve margin, and consequently the market design tends to be complex. The mistakes in market design could make the cost of capacity higher than necessary.

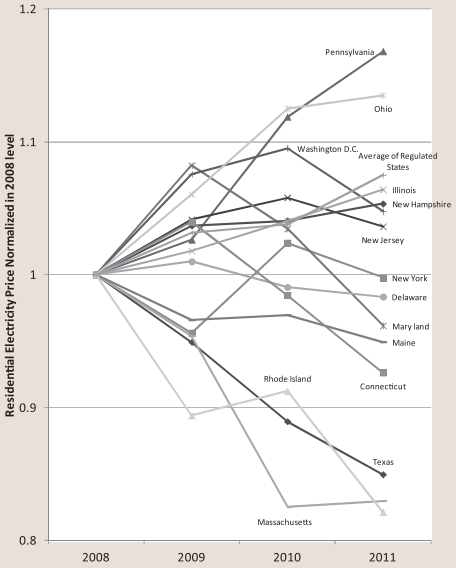


Fig. 2: Development of retail electricity prices after 2008 in liberalized states in the U.S.

In the U.S. electricity retail market for residential customers, the switch from regulated supply to competitive supplier has increased due to the lower wholesale market price, but retail prices have not necessarily lowered. Since 2008, electricity prices in Maryland and Connecticut have fallen, but the prices in these states had increased drastically up until 2008, and liberalization has not yet brought about lower prices.

Table 1: Issues concerning the regulated retail prices after liberalization in France, Germany, and the U.K.

By examining the UK, France, and Germany, we showed the issues concerning the regulated retail tariffs for residential customers after liberalizations. Many European countries such as France still maintain regulated tariffs, and in some countries, low prices of regulated tariffs prevent customers from shifting to market tariffs, and deter competitions. The European Commission requests these countries to abolish regulated tariffs, and, recently, show their firm opinion against such tariffs with a view to initiate infringement cases in the European Court of Justice.

Issue	Country	Current Status and Evaluation
Price levels of transitional regulated tariff and last resort service	France	Low-priced regulated tariffs prevent residential customers from switching to market tariffs, and adversely affect the competition.
	Germany	Default (last resort) tariffs are set slightly higher than the market tariffs, which urges residential customers to switch to market offers.
Reversibility of residential customers to regulated tariff	France	Residential customers cannot move back to the regulated tariff once they switch to market tariffs, which makes switching customers face price risks.
Deadline of the Abolishment of Regulated Retail Tariffs	France and others	The politicians and regulatory authorities cannot decide the abolishment of regulated retail tariffs because of potential opposition from customers.
Customer Protection Measures after the Abolishment of Regulated Retail Tariffs	The United Kingdom	While customer protection measures such as discounted tariffs for low-income customers were introduced, theoretical and practical problems are revealed.

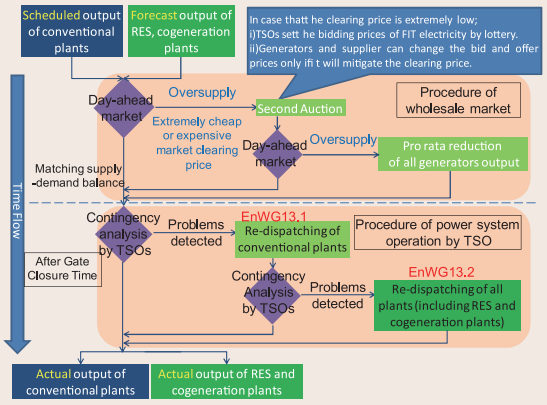


Fig. 3: The schematic procedure of spot market clearing and re-dispatching consideration of RES in Germany

When the market clearing price becomes under minus 150 [EUR/MWh], the "second auction" of day-ahead market is opened. In the "second auction", the bid and offer prices of transmission system operators (TSOs) are set randomly. In case that network constraints occur after the gate closure time, TSOs administer a two-step re-dispatching order based on articles 13.1 and 13.2 of the Energy Industry Act (EnWG: Gesetz über die Elektrizitäts- und Gasversorgung). The first-step re-dispatching order based on EnWG 13.1 could be issued for conventional generators. Only when the first-step order could not solve network constraints, the second-step re-dispatching orders based on EnWG 13.2 could be issued for all types of generators including RES and co-generators.

Priority Subjects — **Establishment of Optimal Risk Management**

Analysis for Energy Saving and Environmental Policy – A Harmonized View of Economic Rationality and Energy Security

Background and Objective

Electricity saving activities were eagerly enhanced when Japan experienced serious electricity shortages after the Great East Japan Earthquake in 2011, and there is high expectations for the popularization of renewable energy through the introduction of the feed-in tariff. However, the continuity of electricity saving activities and cost effectiveness of FIT have not yet been fully investigated. As for global warming countermeasures, there will be discussions on voluntary and sustained improvements by the Federation of Economic Organizations and others, and on introduction of emissions trading. This research project aims to provide empirical findings on electricity saving, renewable energy and global warming countermeasures in view of economic rationality and energy security, and to contribute to the establishment of appropriate policies.

Main results

1 Surveys on electricity saving activities after the Great East Japan Earthquake

In order to analyze the electricity saving activities after the Great East Japan Earthquake, we conducted questionnaire surveys targeting households and firms in the summers of 2011 and 2012 (Y12023) (Y12026). In the Kansai region, where a governmental target electricity demand target reduction was introduced, the actual reduction rate and implementation rates of saving measures rose, while in the Tokyo region, where the Electricity Saving Order was abolished, those rates decreased (Fig. 1). In general, however, electricity saving activities are persisting to a large extent. The intention of companies to save electricity in the future was also strong (Fig. 2).

2 Estimation of additional costs for Japan's renewable electricity support policies

This study examined purchased output and total output from 2003 to 2012 under the renewable energy support policies—RPS, photovoltaic (PV) FIT, and FIT—that have been implemented in Japan (Y12034). Additional costs are the costs derived by subtracting variable costs (such as fuel expenses of power-generation departments made redundant due to purchasing) from total purchases of renewable energy. Comparing 2012, around the time when FIT began to recover costs, and 2010, we see that while total purchased output only doubled, additional costs swelled more than five-fold (Fig. 3). This is due to the fact that implementing PV-FIT and FIT has raised the purchase price of PV and expanded purchase targets to include existing facilities.

3 Case studies on Voluntary Action Plans (VAPs) conducted by comprehensive Japanese business associations

According to interviews with relevant individuals in selected business associations, we verified the role of VAPs and their substantial impacts. Through activities based on the VAPs, industrial associations underwent periodic reviews, which are useful to obtain in-depth information on energy use, the replacement of facilities, and other business activities across the whole industry. Such information was not merely collected, but also distributed among member companies and utilized to improve individual activities, especially for those of large enterprises. Our interview data also suggested that VAP have at least modest impacts in terms of facilitating the behavior of small and medium-sized enterprises, who, in general, face difficulties improving energy efficiency due to lack of both capital and labor resources. Our major findings are reported in a book titled "Voluntary Actions for Mitigating Climate Change".

4 Post-2020 international regime for addressing climate change

COP17 decided that, by 2015, parties shall decide on a new climate regime applicable from 2020. We have examined preceding studies on long-term mitigation scenarios and new frameworks the parties proposed (Y12012). We found that some recent studies show scenarios which have a higher range of emissions levels for the first half of the century but still contain the temperature increase beyond pre-industrial level within approximately two degrees Celsius. We also find parties have divergent views, which we categorized as international obligation, pledge and review, and historical responsibility, and we consider convergence of these into one as being difficult (Table 1).

Other reports: (Y12035)

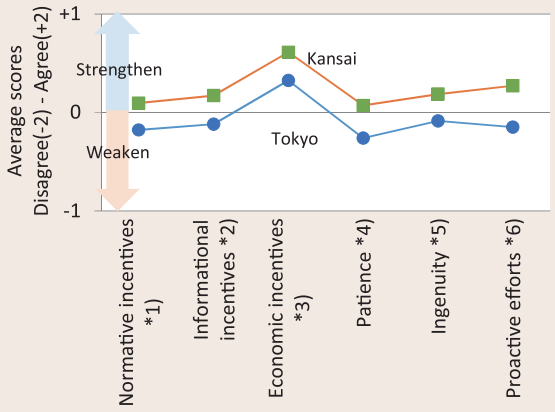


Fig. 1: Change of electricity saving activities in household from summer 2011 to summer 2012

In the Kansai region, motivation and activities for electricity saving in households intensified in summer 2012 compared with 2011. On the other hand, in the Tokyo region, only economic incentives increased due to the rise in electricity rates, while normative and informational incentives decreased. Patience in summer 2012 was either less intensified or around the same as in 2011.

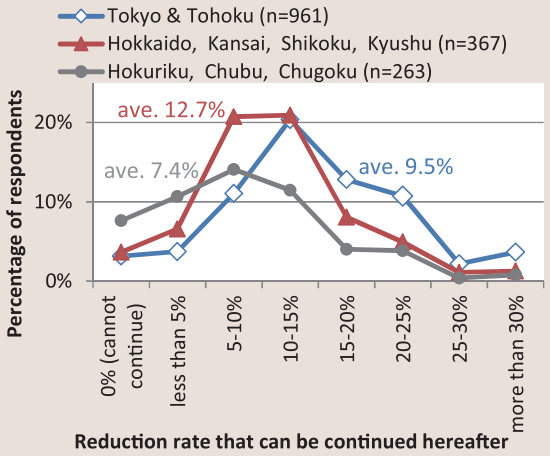


Fig. 2: Intention of companies to continue saving electricity

We asked companies how much reduction of electricity could be continued if saving electricity was required, but without numerical targets set by the government. Responses varied by region. Maintaining a 7% to 12% reduction was considered to be possible. Note that activities and reduction rate of electricity saving can be affected by requests from the government and utilities, thus the result here does not necessarily show a reduction rate that is likely to be achieved in the future.

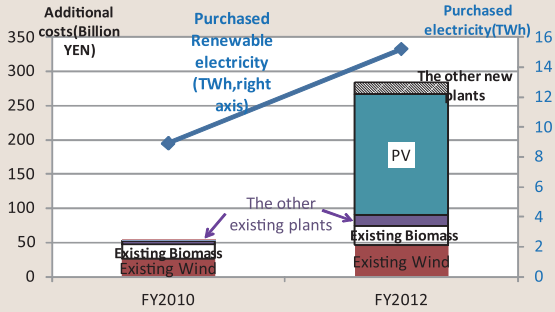


Fig. 3: Comparison of total purchased electricity and additional costs in FY2010 and FY2012

Parties have divergent views that we categorized as international obligation, pledge and review and historical responsibility. We analyzed conflicting points of (1) whether the dichotomy of developed and developing countries should be maintained or revised and (2) whether parties' mitigation efforts should be determined internationally or domestically, indicating that convergence is difficult.

Table 1: Three typical views addressing the Post-2020 international framework on climate change

With the launch of a feed-in tariff (FIT – July, 2012), together with a renewable portfolio standard (RPS-2003) and a photovoltaic FIT (November, 2009), three renewable electricity support policies have temporarily coexisted in Japan. Total purchases and additional costs in 2010 when only RPS was in effect were 8.9TWh and ¥52.0 billion, respectively. Meanwhile, PV-FIT began in 2011 and FIT in 2012. Purchased output and total additional costs in 2012 were 15.2TWh and approximately ¥280.0 billion. In short, comparing 2010, when only RPS recovered costs, and 2012, when both PV-FIT and FIT were in effect, purchased output doubled while additional costs swelled more than five-fold.

Category	View
International Obligation (EU, small island Developing States, etc.)	Cap each countries ' emission so that global temperature does not increase more than 2 degrees Celsius. Revise the dichotomy of developed and developing countries, and allocate caps according to each countries' capability and politics.
Pledge and Review (US, Japan, Russia, etc.)	Voluntary pledge targets/approaches and review them internationally. Revise the dichotomy of developed and developing countries, and allocate caps according to each countries' capability and politics.
Historical Responsibility (China, India, Saudi, etc.)	Emphasize on emission after the industrial revolution and stricter cap on developed countries. Developing countries lower emission with assistance of developed countries. Maintain the dichotomy of developed and developing countries.

Priority Subjects — **Establishment of Optimal Risk Management**

Scientifically and Economically Rational Scenarios to Reduce CO_2 Emissions

Background and Objective

Although we do not have a clear outlook for the national energy policy, the reduction of CO_2 emissions is a major issue in an international framework as it was before the Great East Japan Earthquake. We therefore need to show appropriate direction for the development of low-carbon technologies, leading to emissions reduction, based on the latest trend of technologies and their potential risks.

This study aims to forecast restrictions on world CO_2 emissions with technology basis and economical rationality, and to contribute to establishment of long-term national energy policy. We also conduct preliminary assessment of environmental risks regarding CO_2 capture and storage (CCS) in order to discuss the future introduction of CCS technology.

Main results

1 A rational and feasible pathway of CO_2 emissions reduction based on a new concept of climate stabilization

We have presented a CO_2 emissions pathway, termed Z650*1, designed on the basis of a new climate stabilization concept, and discussed its consequences and issues from a viewpoint of feasible measures to mitigate global warming (V12007). The amount of CO_2 emissions in 2050 for Z650 is 74% of 2000 levels, which is much greater than the 34% required for a conventional pathway (Fig. 1). The Z650 pathway is recognized as a flexible alternative toward the 2°C-target*2, providing more room for reaching an agreeable compromise between developed and developing countries. However, Z650 would see a relatively large increase in temperature during the 21st century (comparison between dotted and solid lines in Fig. 1), necessitating adaptation measures to climate change. Regarding adaptation issues, we have surveyed examples of recent and ongoing strategies and initiatives in leading overseas countries and summarized the general outlook for electric industry in Japan (V12008).

2 Long-term analysis of CO_2 reduction technologies by an integrated assessment model (BET)

BET, developed in FY2011, is our integrated assessment model that includes components of energy, environment (climate), and economy in order to evaluate the importance of CO_2 reduction technologies and their economic impacts. A defining feature of BET, compared with the other models, is that it is superior in handling various end-use technologies that convert final energy into energy service. In FY2012, we have evaluated CO_2 reduction technologies with BET under greenhouse gas constraints and showed that a combination of electrification and advanced end-use technologies (such as heat pump water heater and electric vehicles) would be one of the rational measures to reduce greenhouse gases in the long term (Fig. 2). Also, to have the BET outcome recognized in international modeling communities, we have joined the Energy Modeling Forum 27 modeling exercise (EMF27), which facilitates inter-comparison of over 10 integrated assessment models. The results of EMF27 will be cited in the fifth assessment report of the IPCC published in 2013-2014.

3 Analysis of potential environmental risk by introducing CCS technology

Although CCS technology is one of the important mitigation measures for global warming, scientific understanding of environmental and health risks caused by CCS is not sufficient in Japan. To evaluate the potential environmental impact of CCS technology, we have performed a life cycle assessment (LCA) regarding a pulverized coal power plant in Japan. The results suggest that, while widespread CCS technology decreases global warming impact through the substantial reduction of CO_2 emissions, the use of monoethanolamine (MEA) solvent increases environmental impact, which occurs in processes of MEA production and CO_2 capture (Fig. 3) (V12012).

*1 A CO_2 emissions pathway that allows cumulative total of 650 GtC during 21st century and aims to attain zero in the middle of the 22nd century.
*2 An aspiration goal to limit the global mean temperature to 2°C above preindustrial (around 1750) levels.

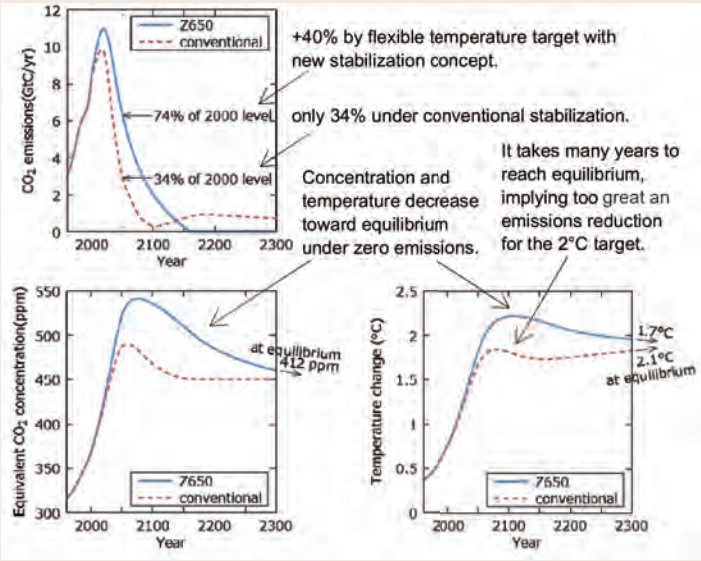


Fig. 1: Comparison between new zero-emissions stabilization (Z650) and conventional concentration stabilization

Results from calculation with our simple climate model (SEEPLUS). Equivalent CO_2 concentrations in the lower left panel represents concentrations converted from the total forcings including non-CO_2 agents. The conventional stabilization toward a constant concentration of 450 ppm, corresponding to 2°C warming, requires substantial emissions reductions during the 21st century. In contrast, Z650 allows more emissions during the 21st century due to a long-term decrease in concentrations resulted from zero emissions after the middle of the 22nd century.

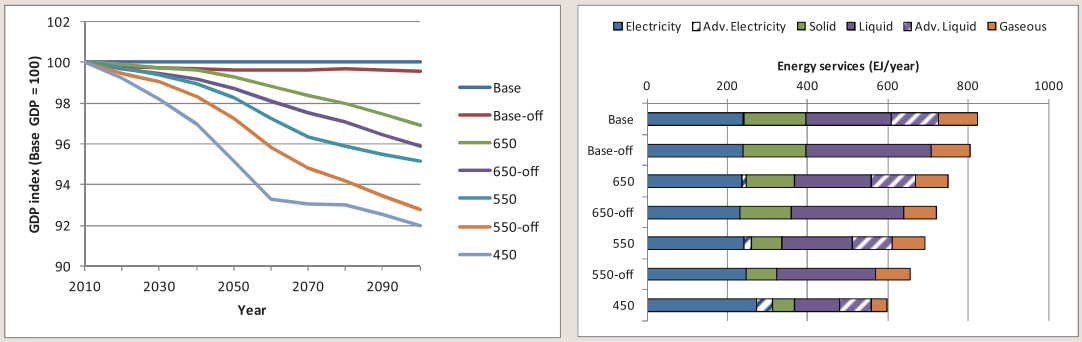


Fig. 2: Global GDP changes and energy service demands in 2050 under constraints of greenhouse gas (GHG) emissions

Results from calculation with our integrated assessment model (BET). "Base" means the case without GHG constraints, numbers in labels, such as 650, indicate constraints of GHG concentration in ppm in CO_2 equivalent, and "off" indicates the results without advanced end-use technologies, such as heat pump water heater, electric passenger vehicles, and hybrid freight vehicles. The stricter the GHG constraints are, the larger the GDP losses are; the GDP losses are mitigated by the advanced end-use technologies (left panel). When the GHG constrains are strict, the energy service demands decrease but the electricity demands are stable in contrast (right panel). "Solid", "Liquid", and "Gaseous" mean the forms of secondary energy.

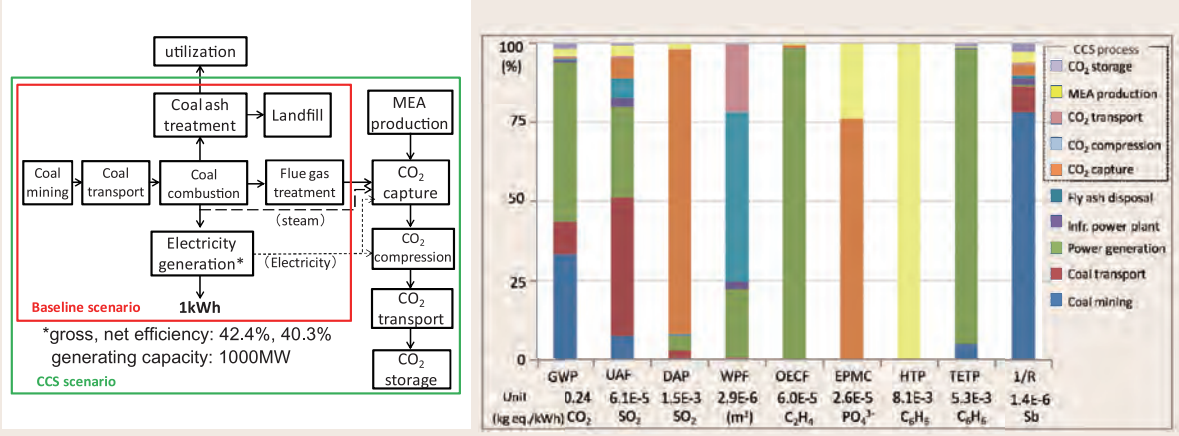


Fig. 3: LCA of a pulverized coal-fired power generation with CCS technology in Japan

The left panel shows LCA system boundaries for base and CCS cases. Dashed/dotted arrows show steam/electricity flow from power plant to CO_2 capture and compression processes. The right panel shows the magnitude of impact in terms of reference substances and its breakdown by processes, categorized into 9 environmental areas: global warming, urban air pollution, acidification, waste, photochemical oxidant, eutrophication, toxic chemical, biological toxicity on terrestrial, and resource consumption, labeled by GWP, UAF, DAP, WPF, OECF, EPMC, HTP, TETP, and 1/R. Introducing CCS technology results in a relative increase in impact caused by MEA production and CO_2 capture processes.

Priority Subjects with Limited Terms — **Establishment of Optimal Risk Management**

Safety Assessment of LWR Systems

Background and Objective

In order to acquire social receptivity for nuclear power generation and continue operation, it is necessary to make ongoing improvements and introduce the latest knowledge for enhancement of safety based on the experience of the Fukushima Daiichi nuclear power plant accident. It is necessary to perform simulations using models which can assess detailed phenomenon and make quantitative risk evaluations of important hazards to clarify the potentially vulnerable portions for evaluation of additional equipment in regards to safety improvement, especially from an engineering viewpoint. In this subject, we aim to contribute to the safety and stable operation of LWRs, through quantitative evaluation and the sophistication of evaluation systems.

Main results

1 Evaluation on characteristics of severe accident analysis codes

We have completed input decks preparations of typical PWR and BWR plants for the latest version of severe accident analysis codes, MAAP*1 ver5 and MELCOR*2. Main accident sequences were analyzed by MAAP ver5 (Fig. 1) and calculation results were compared with previously obtained results by MELCOR code. It was confirmed that the input deck for MAAP code was appropriate for severe accident evaluations. Based on quantitative comparison of calculation results between MAAP and MELCOR*3, we also found that there are differences in the progression of molten core – concrete interaction (Fig. 2) and the failure mode of a containment vessel*4.

2 Evaluation of a spent fuel pool in a severe accident

In light of the Fukushima Daiichi nuclear accident, creating measures against severe accidents for a spent fuel pool is also a task which requires attention. As such, spent fuel pool accident analyses using MAAP 5 were performed to quantitatively understand event sequence of both loss-of cooling due to total station blackout and loss-of-pool water accidents. These analyses revealed that there is enough time to implement measures until fuels are uncovered in the case of a loss-of-cooling accident (Fig. 3). It is also revealed that fuel temperature increases, however, it can be cooled by natural circulation of air when the decay heat power of fuel assemblies is small in the case of a loss-of-coolant accident.

3 Evaluation on hydrogen/vapor ventilation in a BWR reactor building

We analyze the behavior of hydrogen, which is generated from a RPV (reactor pressure vessel) and moves through a PCV (primary containment vessel), in a BWR (boiling water reactor) building using CFD (computational fluid dynamics) code. A uniform distribution of hydrogen and temperature is obtained. With the assumption of uniformity, we developed a lumped system to evaluate hydrogen density of the building. The system can be adopted to evaluate not only hydrogen but also vapor generated from SFP (spent fuel pool).

4 Development of the level 1 PRA models for NPPs in consideration of common cause failures caused by external events

Level 1 PRA (probabilistic risk assessments for the estimation of core damage frequencies) models for the typical BWR and PWR were developed in consideration of the effects of internal events and seismic hazards to analyze the vulnerability of the nuclear power plants to the natural hazards such as seismic and/or tsunami events.

*1 MAAP: The severe accident analysis code being developed by EPRI (U.S.). It is mainly used by electric utilities.
*2 MELCOR: The severe accident analysis code being developed by U.S.NRC. It is mainly used by the regulation side in Japan.
*3 "Development of Level-2 seismic PSA methodology", JNES/SAE06-087, Japan Nuclear Energy Safety Organization (JNES), (2006)
*4 R.Hiwatari, et al., 8th Japan-Korea Symposium on Nuclear Thermal Hydraulics and Safety (NTHAS8), 2012-2

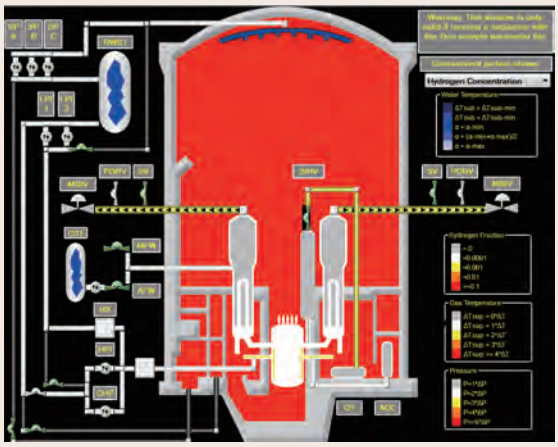


Fig. 1: Analytical model and graphics of calculation results for a typical PWR plant in the MAAP code

This figure shows an analytical model of a core, primary/secondary coolant systems and a containment vessel for a 4-loop-type PWR with dry containment in the MAAP code. Analytical results of temperature and pressure in the containment vessel and the coolant system loops are indicated by color mapping.

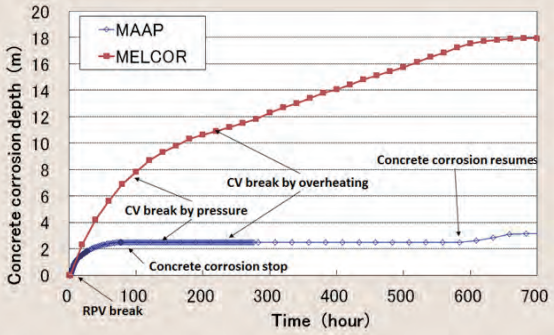


Fig. 2: Comparison between codes of the concrete corrosion depth in a containment vessel (CV) about the accident sequence "large rupture LOCA + feed water failure" in a PWR representation plant

The difference in the concrete corrosion depth in a CV following the breakage of a reactor pressure vessel suggests a difference in the physical model relating to molten fuel-concrete reaction, debris movement within the CV, etc.

* The result of MELCOR is created from reading values of the report "Development of Level-2 seismic PSA methodology", JNES/SAE06-087, JNES, (2006)*3

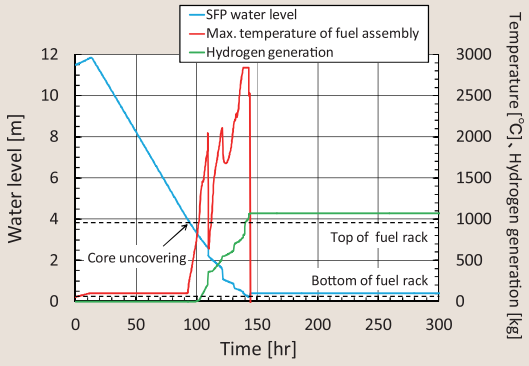


Fig. 3: Evaluation of spent fuel pool in a loss-of-coolant accident due to station power outage

A spent fuel pool accident analyses using the integral severe accident code "MAAP" were performed when the spent fuel pool loses its cooling function in the event of a station power outage. From these analyses, it is confirmed that there are about 89 hours until the fuels are uncovered under the severe thermal condition that the half of the spent fuel pool inventory is consisted of the fuel assemblies with cooling times of only 7 days after discharge from the core (Maximum burn up is 45,000 MWd/t, decay heat power is 8.6 MW).

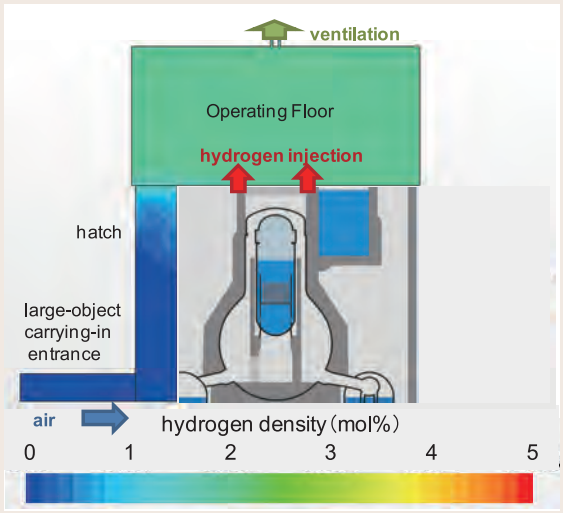


Fig. 4: Calculation on hydrogen behavior in BWR building

Three dimensional CFD analyses (static and transient) is conducted to evaluate hydrogen behavior in a BWR building. The hydrogen leaks from a PCV to the operating floor, mixes with the air from outside and is vented from the top outlet.

Priority Subjects with Limited Terms — **Establishment of Optimal Risk Management**

Improvement of Safety Assessment Technologies on External Natural Hazards for Nuclear Facilities

Background and Objective

The Fukushima Daiichi nuclear accident has seriously impacted upon the reliability of nuclear safety and social trust. Most nuclear power plants are currently shut down for these reasons. Long term shutdown should be avoided as nuclear power has the potential to play an important role for realizing a low carbon society. In this project, safety assessment methodologies for nuclear power plants subjected to natural disaster are studied.

Main results

1 Development of a simple method for estimating tsunami hydrodynamic loads

In order to evaluate the fragility of facilities and structures against great tsunamis, a novel and rational method for estimating tsunami hydrodynamic loads was proposed. By using the proposed method, tsunami hydrodynamic loads can be estimated simply and accurately from the specific energy of tsunami flow. Hydrodynamic loads predicted by the method were compared with those obtained by three-dimensional numerical simulations using the computational fluid dynamics code SLOSH-NAGARE, showing good agreement between them (Fig. 1). The proposed method will be validated under a wide variety of conditions in the future.

2 Verification analysis of an evaluation method for rock mass attainment area due to slope collapse

An evaluation method of rock mass attainment area due to slope collapse is developed to research the influence of peripheral slope collapse of nuclear facilities on safety. This evaluation method is based on numerical analysis by a three-dimensional distinct element method (DEM) assuming rock mass collision and rebinding during a slope collapse. Numerical simulation of a slope collapse by shaking a table was conducted to verify the analysis method. For this simulation, rock mass models which express the three-dimensional proportions of the rock mass used in the experiment are created and a set-up procedure of analytical parameter based on coefficients of restitution and friction is suggested. As a result, the volume of falling rock mass and attainment area by experiment are successfully reproduced and validity of our analysis method is shown. The remaining issue is on-site slope collapse analysis.

3 Development of equipment for obtaining fault samples by large-scale rotary tube sampling

The purpose of this research is to improve reliability of the stability evaluation method of the ground foundation and surrounding slope of a nuclear power plant. We developed sampling equipment which obtained undisturbed fault samples 20cm in diameter to investigate the mechanical properties (two patent applications). The features of the equipment are that rotary motors are installed immediately above the core barrel to suppress rotational vibration, a rubber sleeve is placed on the core in the core barrel to enable direct installment in a tri-axial apparatus and the lower end of the core is cut and retrieved by the core bits divided into three parts which arch out into the lower end. The performance tests of the equipment were carried out on tuffaceous rock in a laboratory. We will conduct sampling in the field to test the effectiveness of the equipment.

4 Development of numerical simulation for eruption columns to improve assessment of volcanic ash-fall

The numerical assessment method of volcanic ash-fall is improved through the development of simulation on an eruption column and transport and diffusion of volcanic ash-cloud and ash-fall. The non-linear, three-dimensional simulation of an eruption column was developed. For the simulation of real-scale eruption columns, the eruption cloud shape varied with the velocity at the vent. Moreover, the turbulent model considerably affected the simulation results for real-scale eruption columns (Fig. 4, N12003).

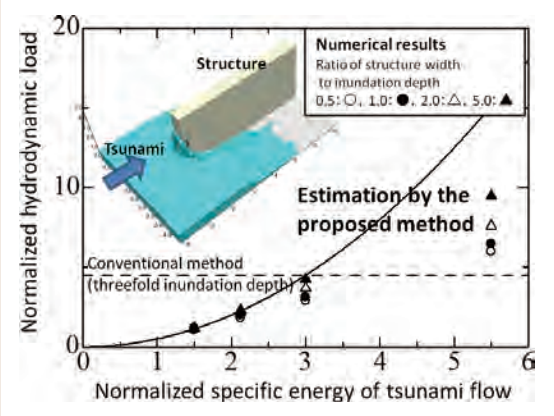


Fig. 1: Comparison between tsunami hydrodynamic loads predicted using the proposed method and those obtained by three-dimensional numerical simulations

In order to validate the proposed method for estimating tsunami hydrodynamic load, three-dimensional numerical simulations of a tsunami were carried out and the hydrodynamic loads on a structure were calculated with four ratios of the structure width to tsunami inundation depth and four Froude numbers. The comparison in the figure confirms the validity of the proposed method and the hydrodynamic load predicted by the conventional method, in which the hydrodynamic load is expressed as a hydrostatic load of threefold inundation depth, is overestimated in the low tsunami energy regime.

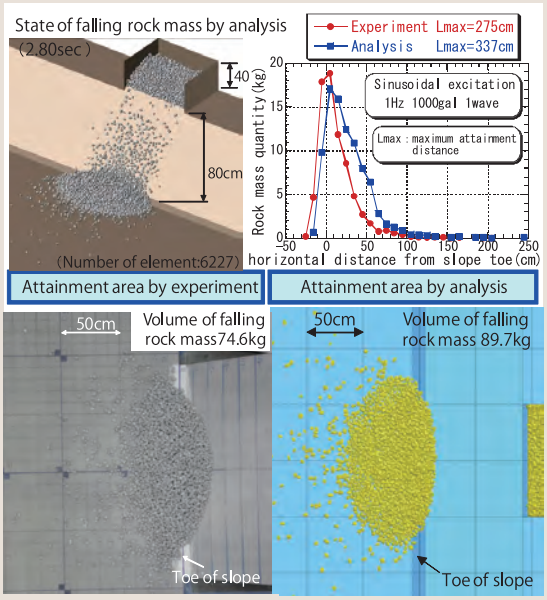


Fig. 2: Verification of evaluation method of rock mass attainment area due to slope collapse by numerical simulation of shaking table test

For verification of the evaluation method of rock mass attainment area due to slope collapse, a numerical simulation of a shaking table test was conducted. As a result, the volume of falling rock mass and attainment area by experiment are successfully reproduced and the validity of our analysis method is shown.

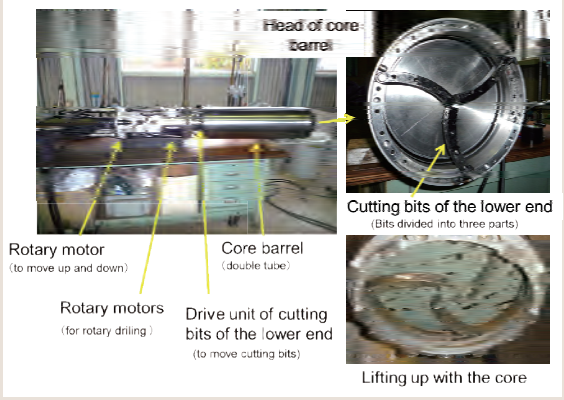
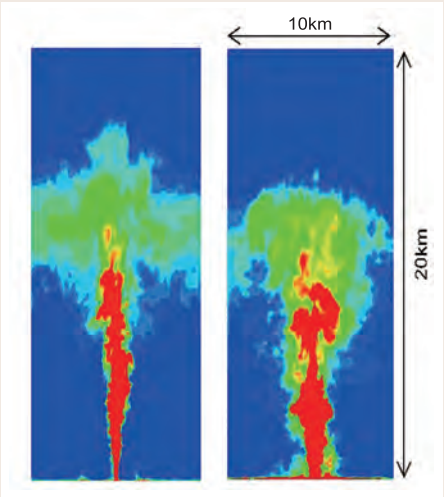


Fig. 3: Sampling equipment using a large-scale rotary tube

We proposed and developed sampling equipment to obtain undisturbed fault samples 20cm in diameter (two patent applications). We successfully experimented with a prototype on the tuffaceous rock in the laboratory and verify the cutting of the lower end of the core and insertion of the core into rubber sleeve.



(a) Smagorinsky model, (b) Yuu model
Velocity at vent is 200m/s for both models.

Fig. 4: Effect of turbulent model on eruption column shape

The volume fraction of volcanic ash particles within the eruption column is calculated by the developed turbulent model. The simulation results show that the selection of turbulent model significantly affects eruption column shape.

Priority Subjects with Limited Terms — **Establishment of Optimal Risk Management**

Assessment of Radioactive Material Diffusion in the Environment and its Remediation Effectiveness

Background and Objective

Preliminary assessments must be carried out on the environmental impact of radioactive materials on the atmosphere, ocean, and groundwater in the case of severe accidents as well as the effectiveness of preventive measures against nuclear power plant accidents in order to evaluate and continuously improve the safety of nuclear power plants.
The target of this study is to develop techniques for predicting the dispersion of radioactive materials into the atmosphere, ocean, and groundwater as well as for monitoring radioactive materials and assessing the migration of radioactive materials in marine organisms and forests. Through the development of these techniques, we aim to contribute to improving the safety of nuclear power plants through the assessment of environmental impact.

Main results

1 Developing assessment techniques for the atmospheric diffusion of radioactive materials

An atmospheric transport model for wide areas has been developed to simulate the transport and deposition of radioactive materials to the ground surface. The long-term cumulative amount of radioactive materials, released from Fukushima Daiichi Nuclear Power Plant and deposited on the ground surface, has been estimated (Fig. 1). Models for wet and dry deposition were also incorporated into another dispersion model used to assess the safety of nuclear power plants over relatively small areas. Such added features have enabled the developed model to be used for estimating the amount of deposited radioactive materials during the safety assessment of nuclear power plants.

2 Developing assessment techniques of ocean diffusion of radioactive materials and transfer to marine organism

The amounts of ^{137}Cs, ^{134}Cs, and ^{131}I directly released from Fukushima Daiichi Nuclear Power Plant were estimated from the results of monitoring the adjacent sea. On the basis of the estimation results, the oceanic dispersion of these radioactive materials over wide areas off the coast of Fukushima was simulated by considering the fallout of materials from the atmosphere. The simulation results were in good agreement with the monitoring results for the target area (Fig. 2).*1 Concentrations of the radioactive cesium in marine organisms were estimated using a food chain transfer model. A simulation showed that decreases of the calculated concentrations over time in plankton feeding fish such as Japanese sand lance and carnivorous fish such as olive flounder were similar to those observed in the monitoring results (Fig. 3).*2 The estimated amounts of directly released radioactive materials were reported by TEPCO to the Nuclear and Industrial Safety Agency and are also included in the report by the Investigation Committee on the Accident at Fukushima Nuclear Power Stations of TEPCO.*3

3 Development of a method for predicting migration of radioactive materials in ground

A numerical simulation method has been developed to assess accurately the migration behavior of radioactive materials in ground by groundwater via groundwater as a transport medium. The developed method was applied to the simulation of groundwater flow and migration of radionuclides at a model site over several decades. In the future, the method can be used to evaluate the safety of interim storage facilities and disposal facilities for radioactive wastes.

4 Assessment of the long-term environmental impact of radioactive material

Radiocesium (^{134}Cs+^{137}Cs) concentrations, primarily derived from the Fukushima nuclear power plant accident in March 2011, were measured in litterfalls of cherry and 6 other woody species at Abiko. The concentration in litterfalls of cherry, horse chestnut, and trident maple collected in late autumn was fewer than those collected in early autumn, and the reduction in radiocesium concentration in the litterfall was nearly synchronous with potassium concentrations (Fig. 4). It is possible that this phenomenon occurred due in part to physiological features of the plants which led to a translocation of potassium from leaves to the body/twigs.

*1 TSUMUNE DAISUKE, et al., Biogeosciences Discuss., 10, 6259-6314, 2013 (doi:10.5194/bgd-10-6259-2013).
*2 TATEDA YUTAKA, et al., Journal of Environmental Radioactivity. 2013, vol. 124, p. 1–12.
*3 Report by Investigation Committee on the Accident at Fukushima Nuclear Power Stations of TEPCO, 20 June 2012. http://www.tepco.co.jp/nu/fukushima-np/interim/index-j.html, 2013/3/19

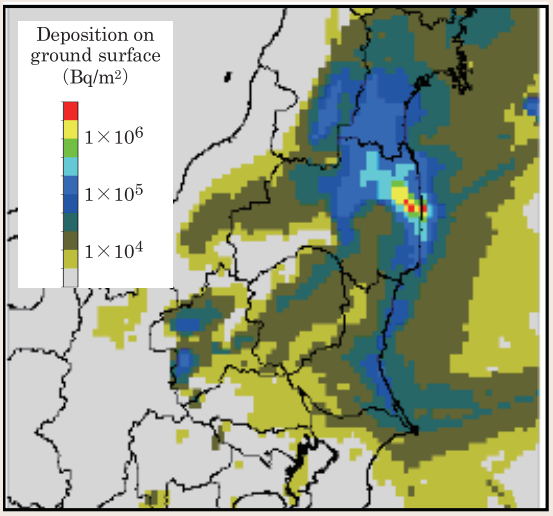


Fig. 1: Example of simulation to determine the cumulative amount of radioactive materials deposited on the ground surface over wide areas using an atmospheric transport model

The cumulative amount of radioactive materials deposited on the ground surface was estimated using a model developed to simulate the concentration and amount of deposited radioactive materials. The estimation is based on detailed meteorological data of March 2011, obtained using a meteorological model, and the amount of released radioactive materials estimated by the Japan Atomic Energy Agency. The simulation reproduced the distribution of the cumulative amount of radioactive materials deposited on the ground surface obtained by aircraft monitoring and the radiation dose monitored at each monitoring point with reasonable accuracy.

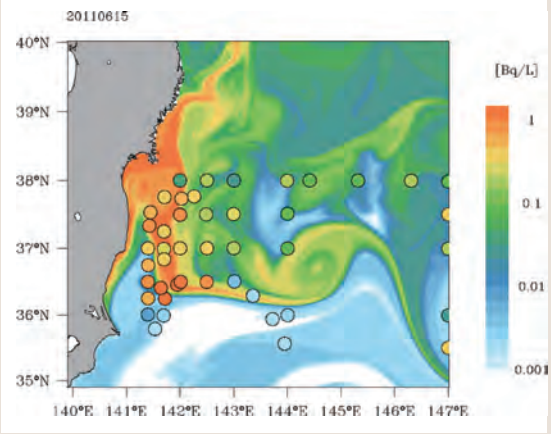
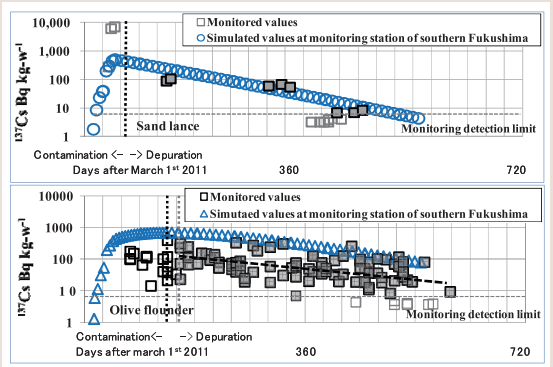


Fig. 2: ^{137}Cs concentration on the ocean surface (off the coast of Fukushima)

The ^{137}Cs concentrations in the ocean in the middle of June 2011 obtained by simulation were in good agreement with the monitoring results, confirming that the concentration distribution is affected by medium-size vortices in the ocean. Color contours represent the simulation results, and color plots represent the monitoring positions and concentrations.



Filled square ■ represents observed values during depuration stage (decrease periods of concentrations).

Fig. 3: ^{137}Cs concentrations in marine organisms obtained by simulation and monitoring (along the southern coast of Fukushima)

Regarding plankton feeding fish such as Japanese sand lance (top) and coastal carnivorous fish such as olive flounder (bottom), the ^{137}Cs concentrations in their muscles, including those resulting from transfer through the food chain, decreased after March 2011 and August 2012, respectively, according to the simulation result, which was similar to the monitoring results. This indicates that the migration processes of radioactive cesium, being governed by their contamination from seawater, transfer through prey ingestion, and excretion from organisms by their metabolism, were accurately simulated by the technique developed to assess the dynamic migration of radioactive cesium in ecosystem.

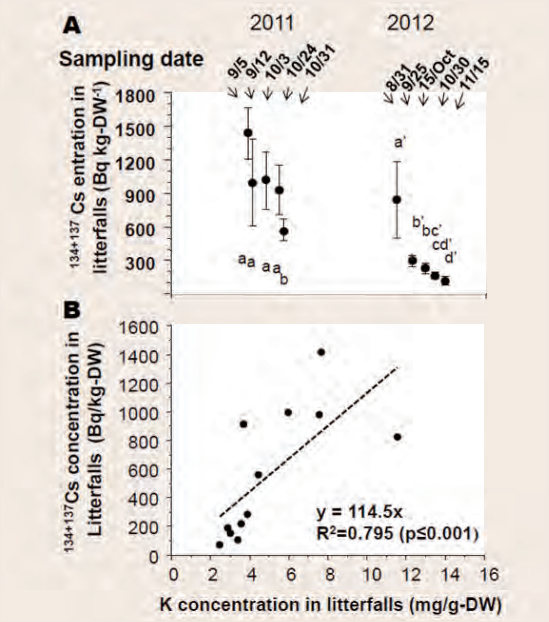


Fig. 4: A correlation between radiocesium concentration and potassium in cherry litterfalls

Radiocesium concentrations in litterfalls of cherry collected between 5 Sep and 31 Oct, 2011, and 31 Aug and 15 Nov, 2012 gradually decreased as the sampling date in successive years (top). A strong correlation is observed between radiocesium concentrations and potassium concentrations in cherry litterfalls (bottom).

Priority Subjects — **Establishment of Optimal Risk Management**

Development of Fire Modeling Methodology for Nuclear Power Plant Applications

Background and Objective

The Japanese government aims to revise the fire protection requirement for nuclear power plant applications, and also expects the early implementation of fire hazard evaluation. As the fire protection design code was based on demonstration fire tests conducted in the late eighties, it is necessary to establish a fire hazard analysis methodology which can withstand business licenses and is based on the analysis of overseas data from recent years.

In this project, we aim to integrate the fire modeling methodology for nuclear power plant applications based on the fundamental fire source tests, and demonstrate countermeasures for the anticipated key issues regarding fire protection, such as high energy arcing fault (HEAF) events, which were identified after severe seismic disasters.

Main results

1 Applicability evaluation of fire impact analysis using a fire model FDS

In fire hazard evaluation, it is necessary to estimate the ignition time or damage time of important safety equipment. One representative fire model, FDS (Fire Dynamics Simulator), is suitable for fire hazard evaluation in complicated geometry compartments and detailed evaluation of fire phenomena, although the results greatly depend on numerical conditions. Sensitivity analyses and simulations reproducing existing experiments of fire plumes, fires in a single room and multiple rooms were performed (Fig. 1), showing recommended grid resolutions and fire-source models (N12019). These results contribute to appropriate estimations of equipment ignition time in various fire scenarios and the development of practical and effective fire protection plans.

2 Heat source characteristics of liquid fuel in a compartment under ventilation conditions

An accurate understanding of heat source characteristics, including fire plume and fresh-air entrainment processes, are indispensable in appropriately setting heat release rates in fire simulations, which provide important information for the evaluation of temperature and smoke transport behavior in fire compartments. Fire tests were conducted to firmly grasp the heat source characteristics of liquid fuel (ethanol) in a compartment under ventilation conditions, which mimics a compartment of a nuclear power plant*1. In these tests, the experimental parameters were pool size and ventilation flow rate. The mechanics of heat release rate reduction due to a lack of oxygen in fresh-air was discussed in detail (Fig. 2).

3 Evaluation of HEAF fire using full scale high-voltage metal-enclosed switchgear components

Successive fire due to a HEAF event in a high-voltage metal-clad switch gear*2 was identified at the Onagawa nuclear power plant after the Great East Japan Earthquake. In light of this, we tested full scale high-voltage metal-enclosed switch gear components (non-seismic and non-arc proof type), and evaluated arcing energy and the possibility of successive fire occurrence (Fig. 3). Furthermore, we analyzed details of internal pressure, damage to a metal enclosure and gas emissions from a broken enclosure using CFD (Computational Fluid Dynamics code) code (Fig. 4).

*1 Fire tests were conducted under the cooperative research agreement with the Tokyo University of Science.
*2 Installed in a metal enclosure with a protective relay (circuit breakers, etc.) and a high-voltage bus to protect and control the power system

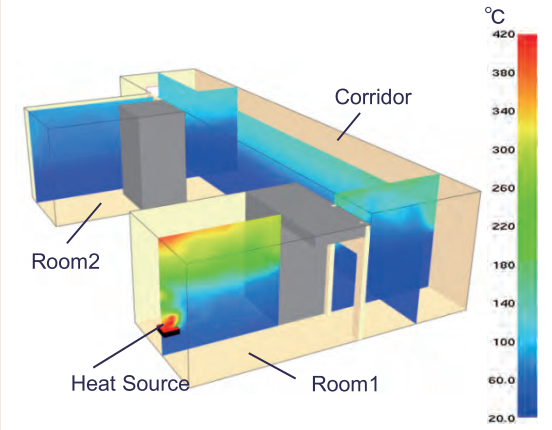
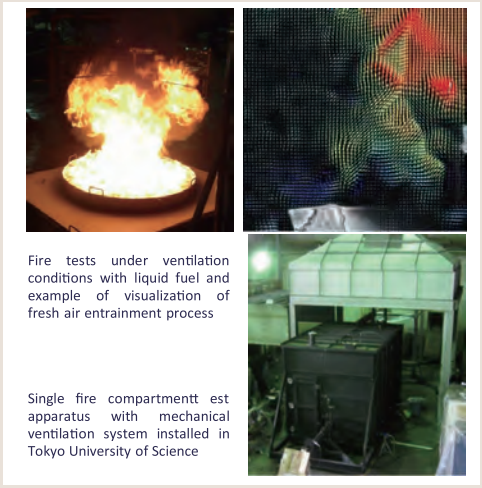


Fig. 1: Example of simulation of multi-room fires using a fire model FDS

In fire impact assessments for fire compartments, it is necessary to set the extent of fire impact and estimate the firing time or injury time of important safety equipment. This requires the rational application of fire models. The fire model "FDS*" gives spatial distributions of physical quantities, such as temperature, velocity, oxygen concentration and their temporal variations. Sensitivity analyses of grid resolution showed that the turbulence intensity of temperature in a fire plume is independent of grid spacing when the grid spacing is smaller than one-twentieth of the flame length scale based on heat release rate.

* A CFD model developed by the NIST (National Institute of Standards and Technology) in the US, which primarily simulates heat and substance transport in fire fields and enables evaluations of spatial distributions of physical quantities such as air temperature.



Fire tests under ventilation conditions with liquid fuel and example of visualization of fresh air entrainment process

Single fire compartmentt est apparatus with mechanical ventilation system installed in Tokyo University of Science

Fig. 2: Heat source characteristics of liquid fuel in a compartment under ventilation conditions

We installed a fire test room (width 2.4m × Depth 3.6m × height 2.4m) with a mechanical ventilation system with consideration to the single fire compartment configuration at the fire test facility located in Tokyo University of Science and initiated a liquid fuel fire with ethanol. As test parameters, various heat source areas (diameter 30, 45, 60cm), locations (central) and ventilation flows(0-100m^3/h)were used. We measured room temperature, inner pressure, heat flux to wall or ceiling, ventilation flow rate, mass loss rate and gas species (O_2, CO_2, CO). Moreover, we analyzed the mechanism of the fire plume and the relationship between the reduced heat release rate and the amount of oxygen entrained by fresh air.

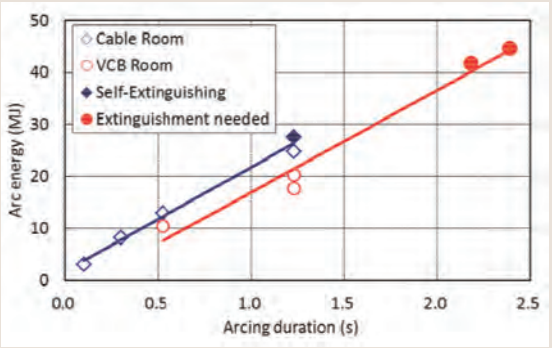


Fig. 3: Ignition conditions between arcing energy and duration measured in the HEAF tests using high-voltage metal-clad switchgears

We measured arcing energy* using a high-voltage metal-clad switchgear (test voltage 7.2kV, three-phase three-wire system, rated withstand current 40kA×2sec, copper bus conductor) in a short-circuit current with 18.9kA and durations of 0.1 to 2.2 sec. When the arcing energy exceeded 25MJ, successive fire was identified. Especially, in the case where the arc flash was discharged in the VCB room, a 2-second arcing duration caused successive fire which required extinguishment.

* Hot gas heated in the metal enclosure due to the arc flash will be emitted out of the enclosure or to adjacent enclosure, and has a potential to damage the surrounding equipment.

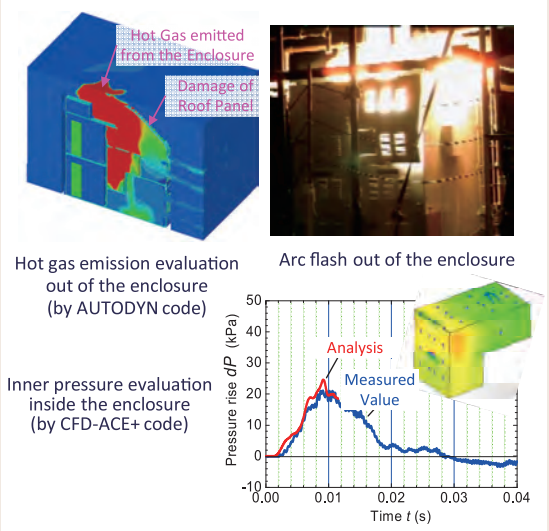


Fig. 4: Estimation of internal pressure and hot gas emission from the damaged enclosure

The arc flash in the upper cable room of the high-voltage metal switchgear heated the air in the enclosure and caused inner pressure. We calculated the pressure rise by using CFD code (CFD ACE+) on the assumption that 53% of measured arcing energy contributes to pressure rise. Results showed that the calculated pressure rise as in good agreement with the measured value. Furthermore, by impact analysis code AUTODYN, we were able to accurately represent propagation of hot gas and damage of the enclosure by modeling compressed gas as an arc flash source which has an energy equivalent energy to 53% measured arcing energy.

Priority Subjects — **Establishment of Optimal Risk Management**

Quantitative Evaluation of Low-Dose Radiation Risk and its Reflection on Radiation Protection

Background and Objective

The environmental contamination by radioactive materials which has arisen from the accident at the Fukushima Daiichi nuclear plant has given rise to public concern regarding radiation exposure, which showed that radiation protection for the general public in such situations have not been adequately developed. An epidemiological research study of residents in high natural radiation areas suggested that there is no increase in radiation risk at a prolonged low-dose-rate, in other words, the existence of a dose rate effect. Properly understanding this effect could contribute to the establishment of rational protection criteria and alleviate public concern regarding radiation exposure.

This project is aiming to construct rational radiation protection systems which achieve accountability to society; specifically to propose for the improvement of protective measures under the situation after accidents, and to elucidate biological mechanisms of dose-rate effect by experimental studies.

Main results

1 Proposal of a radiation protection framework with a graded approach in existing exposure situations resulting from nuclear accidents

The International Commission on Radiological Protection (ICRP) recommends that radiation protection be optimized by the application of reference levels selected according to the situation by taking into account economic and social factors in emergency exposure situations*1 and existing exposure situations*2, whereas dose limits apply to normal planned exposure situations. In this study, a concept of reference level application for optimization of protection in the management of radioactive waste and food safety regulation is proposed in light of the fact that several issues in these sectors were revealed by the accident at the Fukushima Daiichi nuclear power plant.

A radiation protection framework for the management of radioactive waste generated in decontamination is proposed, in which intermediate reference levels for such waste management are adopted gradually according to environmental remediation progress and the reduction in the existing ambient dose, in order to make the waste management activities reasonably practical (Fig. 1). Also graded reference levels are specifically proposed to improve food safety regulations, according to the timeframe and exposure situations after a nuclear accident (Fig. 2).

2 Quantitative analysis of tissue stem cell turnover to elucidate mechanisms for dose rate effects

Cancer is considered to be initiated by an accumulation of lesions in tissue stem cells (TSC*3). We are exerting efforts to clarify mechanisms for dose-rate effects, under the working hypothesis that the effects would attribute to the mechanisms for eliminating damaged TSCs from a living body by cell death and/or turnover.

We established an experimental system to quantitatively analyze TSC turnover after irradiation, focusing on intestinal stem cells, of which the behavior has been well studied (Fig. 3). Using this system, we clarified that the turnover of stem cells in small intestines was stimulated by high dose-rate exposure (Fig. 4). This behavior suggested that cancer risk would increase after high dose-rate irradiation which can make lesions in all cells simultaneous, resulting in a reduction of TSCs and reproliferation of surviving damaged TSCs to maintain tissue function. We will extend the application of this method to clarify the difference in the case of low dose rate exposure, which can induce a small number of damaged cells among healthy TSCs.

*1 Exposure situations that require urgent action to avoid or reduce risks.
*2 Exposure situations that already exist when a decision on control has to be taken. Also include long-term exposure situations following a nuclear or radiological emergency.
*3 Cells in which tissue-forming cells originate. They are also considered as origins of cancer because of their proliferative characters.

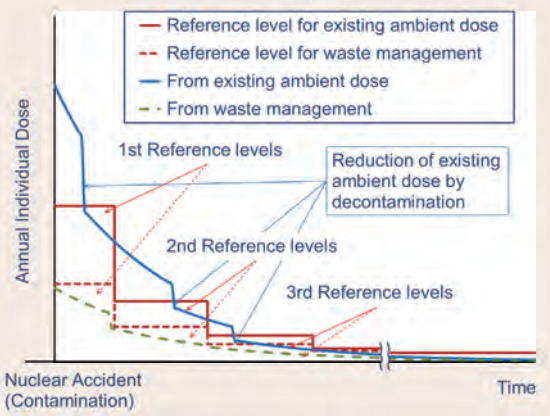


Fig.1: Conceptual diagram of application of intermediate reference levels for waste management in existing exposure situations

Under an existing exposure situation with a certain ambient dose due to contamination resulting from the emission of radionuclides by a nuclear accident, the first reference level for radioactive waste management as a source-related restriction is selected below the reference level selected for the existing annual ambient dose in the environment, taking into account the practicability of the environmental remediation including the waste management. When the existing annual ambient dose is reduced to below the first reference level, the second reference levels for the existing annual ambient dose and for waste management are selected to be lower than the first values. This procedure is repeated on the basis of the principle of optimization until the existing annual ambient dose in the environment is reduced to the normal dose level.

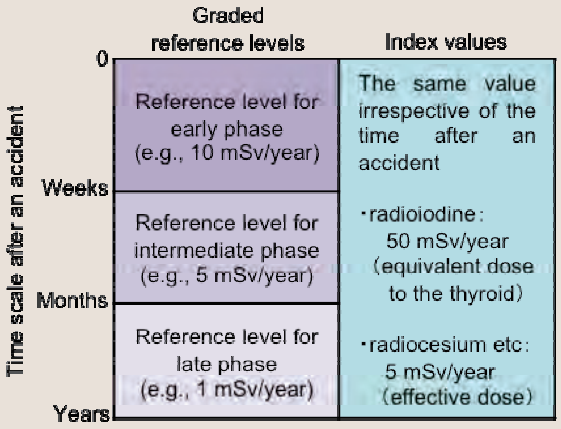


Fig. 2: Comparison of graded reference levels versus index values for food safety regulations

The period of emergency and existing exposure situations are divided into early, intermediate and late phase for which the time scale is in weeks, months and years, respectively, and graded reference level values are assigned for each phase. This approach allows realistic implementation of restrictions on distribution and consumption while the balance between various risks is kept, enabling stepwise reduction of the dose to members of the public. In contrast to index values for which the same values were assigned independent of phases after the accident, implementation of the graded triphasic reference level system permits optimization of the food safety regulation depending on situations of the accident and exposure.

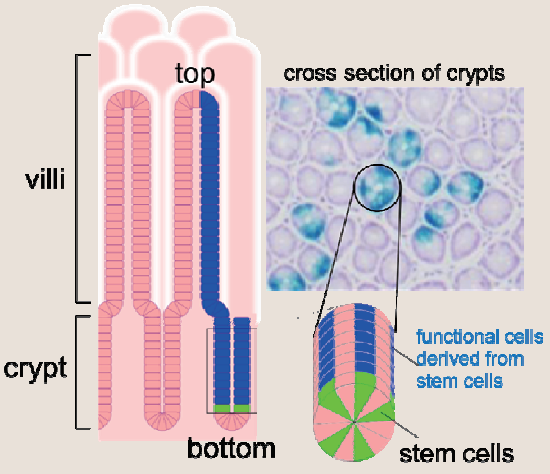


Fig. 3: Experimental system to analyze TSC turnover after irradiation

TSCs and their progenies (functional cells) were visualized as labeled crypts (shown in blue in the figure) from the bottom (crypt) to top (villi) of the intestines of transgenic mice. We found that the percentage of labeled crypts in cross sections could be a useful indicator to understand the frequency of TSC turnover.

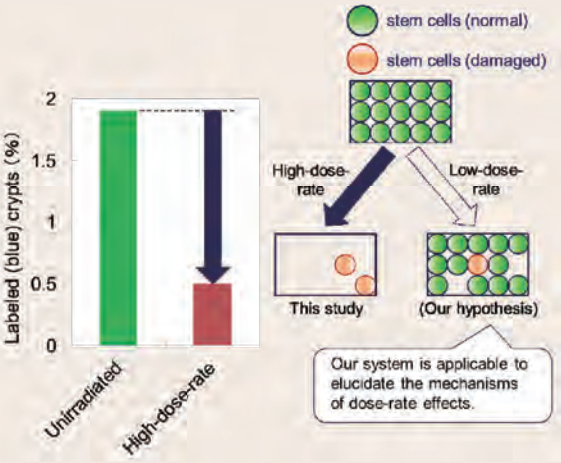


Fig. 4: TSC turnover after high-dose-rate irradiation

The percentage of labeled (blue) crypts in the colon was evaluated after high-dose rate (1.5 Gy/min) X-irradiation (1 Gy). X-irradiation stimulated TSC turnover (loss of TSCs). Since the loss of TSCs has to be reproliferated by surviving (damaged) TSCs, radiation damage induced by high-dose-rate irradiation may accumulate in the tissue cells. On the other hand, we hypothesize that normal TSCs may compensate a loss of TSCs after low dose rate irradiation to prevent the accumulation of radiation damage.

Priority Subjects — **Establishment of Optimal Risk Management**

Development and Systematization of Long-Term Safety Assessments

Background and Objective

For the smooth disposal of the radioactive waste being generated by nuclear power plants, operations must focus on securing safety. As storage capacity of the low-level radioactive waste (LLW) in nuclear plants is growing tight, the licensing safety of pit and sub-surface disposal require review based on a planned schedule. Moreover, in regards to high-level radioactive waste (HLW), the Japanese government is engaged in various efforts such as investigating direct disposal, securing safety in the future, the systemization of site selection and so on.

In this project, R&D of LLW disposal aims to develop methods to evaluate the variation in long-term quality and durability of engineered barriers in order to build a reliable technology. R&D of HLW disposal aims to develop methods to evaluate the long-term stability of the geological environment of a disposal site from the surface.

Main results

1 Evaluation of the durability of a bentonite-based engineered barrier

In radioactive waste disposal facilities, bentonite-based engineered barriers are mainly used for inhibiting the migration of radioactive nuclides. However, since gas permeability of the barrier is very low, it is necessary to evaluate the effect of hydrogen gas pressure, which is generated inside the barrier by anaerobic metal corrosion. Gas migration tests and their numerical simulations are conducted using computer code originally developed by CRIEPI. It was proved that the gas migration tests can be estimated with good accuracy using the computer code (Fig. 1).

The bentonite-based engineered barrier can be altered by alkaline solution leaching from cementitious materials and, as a result, its performance may be affected after a prolonged period. At CRIEPI, we have investigated the mineralogical alteration and the change in permeability of the compacted bentonite under alkaline conditions (Fig. 2). These results were systematically summarized, and future issues were clarified concerning the reduction of uncertainty in the long-term assessment of bentonite properties (N20).

2 Improvement of age estimating method for evaluation of long-term geological stability

Evaluation of long-term uplift is performed as part of the evaluation of geological stability during the selection of HLW disposal sites. It is necessary to estimate the ages of terraces with a sufficient reliability as a criterion of the evaluation. Weathering indexes, such as weathering rind thickness and efficient porosity of terrace gravels, vary greatly, making it difficult to obtain reliable age data. To solve this problem, the application method was revised by careful limiting observation and sampling horizons in a terrace gravel bed. This revision made the weathering index more reliable and applicable to terrace correlation (Fig. 3).

3 Evaluation of long-term behavior in the near-field of a disposal repository

To clarify the long-term behavior of the bedrock and buffer material in the near-field of a disposal repository at the closure stage, centrifugal model tests for which a time-acceleration effect can be expected, have been performed by CRIEPI. The new model test, which considers the heat generation of the HLW, was conducted at a centrifugal force field of 30 G using a 1/30 scale model with a confining pressure of 6 MPa (corresponding to 300 m in depth) and a waste temperature condition of 95°C for 80 d which is equivalent to around 200 years. The result suggested that water distribution in the buffer changes by the influence of the heating of the model waste (Fig. 4). Hence, we will perform further experiments to evaluate the long-term geomechanical behavior in the near-field, by comprehensively considering the coupled thermo-hydraulic-mechanical interaction.

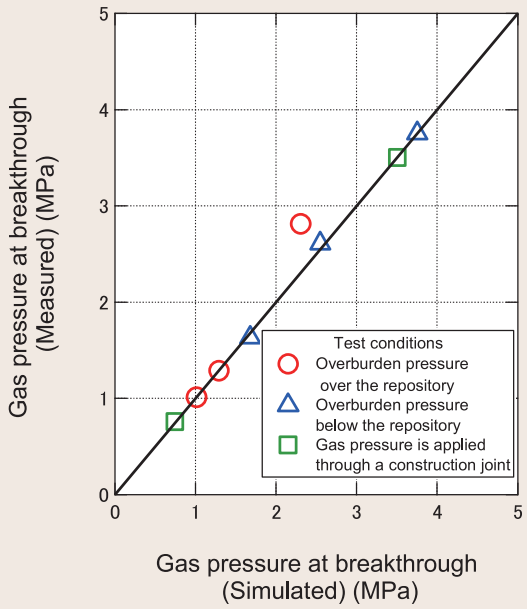


Fig. 1: Relationship between measured and simulated results of gas pressure at breakthrough

In the gas migration tests, overburden pressure right below the repository or right over the repository was applied to the specimen to investigate the effect of overburden pressure on the gas migration characteristics of compacted bentonite. Gas migration tests were also conducted using a test apparatus with a small gas inlet in order to observe the effect of inlet size on test results. Numerical simulation of these test results was conducted using computer code was originally developed by CRIEPI. Fig. 1 shows that the test results can be accurately simulated using CRIEPI's code.

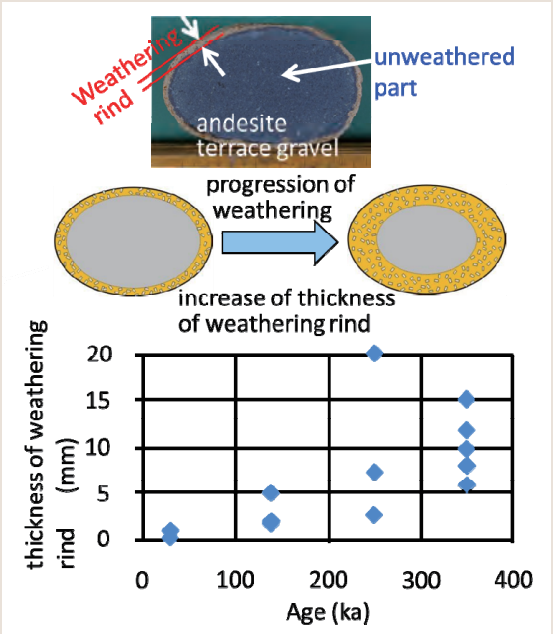


Fig. 3: Relationship between thickness of weathering rind of andesite terrace gravel and terrace age

Weathering rind of andesite terrace gravel thickens with the passage of time. Therefore weathering index enables age to be estimated by the relative sequence of terraces on particular kinds of gravel.

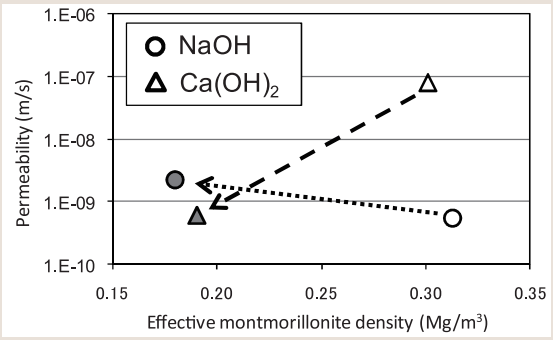
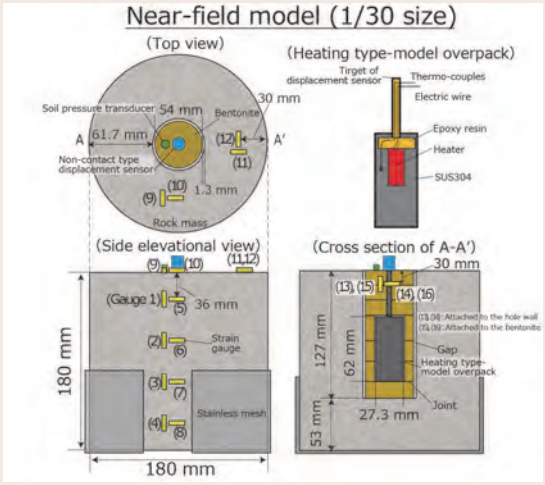


Fig. 2: Change of effective montmorillonite density and permeability of compacted bentonite-sand mixuture during a permeability test using NaOH and $Ca(OH)_2$.

The alteration behavior and change of permeability of bentonite-sand mixture (15 wt% of bentonite) were investigated. In the test using NaOH, the permeability of the sample increased as the effective montmorillonite density decreased. In the test using $Ca(OH)_2$, although the effective monnmorillonite density decreased, the permeability of the sample decreased by more than two orders of magnitude due to the pores of the sample becoming blocked with C-S-H precipitation.



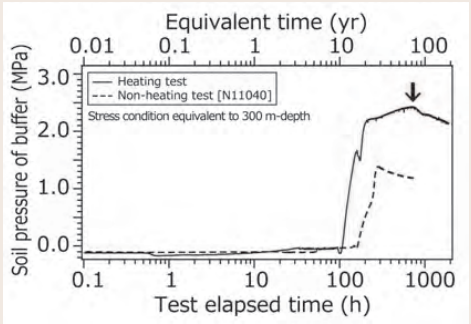


Fig. 4: Long-term centrifugal near-field model test which considers the heat generation of the HLW

The result of a centrifugal near-field model test under "non-heating" and stress-constraint conditions showed that the soil pressure of the bentonite buffer increased rapidly after around 100 h in the elapsed test time, then tended to decrease (dash line). The tendency toward a decrease was interpreted to deform the bedrock and the disposal hole. In contrast, the value of the soil pressure under "heating" and same stress conditions changed to a decrease tendency at the arrow in Fig. 4 (solid line). The flow rate of the injection water also changed at that time. It is inferred that the water distribution in the buffer changes due to heating of the model waste.

Priority Subjects — **Establishment of Optimal Risk Management**

Development of Long-Term Storage Management Technologies for Spent Fuel

Background and Objective

The interim storage of spent fuel by the operation delays of reprocessing facilities serves the important purpose of time adjustment. Up until now, storage using metal casks has been put to practical use, but there are now expectations regarding the practical use of concrete casks from the viewpoint of diversification of storage technology and economic efficiency. Moreover, in response to an increase in demand for radioactive material transportation, there is hope that a new shock absorbing material will be developed to substitute wood, which has been used conventionally.

For the practical use of concrete cask storage, we establish a preventive technology and defect detection method by Non-Destructive Inspection for the stress corrosion cracking (SCC) of the welded parts of the metal canisters used for storing spent fuel and propose a related society standard.

In addition, we examine the applicability of foaming urethane material as a new shock absorbing material for the transportation packaging of radioactive materials.

Main results

1 Verification of preventive measures against SCC occurrence by shot peening

We examine an application of zirconia shot peening (ZSP)* as residual stress improvement processing that is considered to prevent SCC occurrence effectively at the welded part of a canister. As a result of having performed ZSP processing to a full-scale model of canister made of SUS304L, the residual tensile stress in the vicinity of the weld turned to compressive stress in the range of approximately 0.7mm in depth (Fig. 1). In addition, as a result of having carried out SCC examinations for more than 2,000 hours at a temperature of 80℃ and a relative humidity of 35% which are severer conditions than an actual marine environment (temperature of 50℃, relative humidity of 35%), a high number of cracks larger than 100μm occurred in the vicinity of the weld where ZSP was not applied, but cracks were not observed in the area that was processed by ZSP, thereby its effectiveness was confirmed. (N12023)

2 Development of a measurement technique for salt deposits on the surface of canisters for an SCC countermeasure

Since chloride is considered a factor behind the occurrence of SCC, we develop a technique to measure chlorine deposited on the surface of canisters by laser-induced breakdown spectroscopy (LIBS). Although LIBS is expected to measure chlorine concentration with high precision, tensile residual stress may be induced in the metal surface because of laser irradiation and may affect SCC initiation. Therefore, the laser pulses were irradiated on a specimen of canister candidate materials type 304L with typical conditions for LIBS measurement, and we evaluated its influence on SCC occurrence. The tensile residual stress in the irradiated point after laser irradiation ranged around 65μm in depth, and the depth of cracks considered to be SCC occurred due to the corrosion test were 10-40 μm, which is very small compared to the thickness of the canister (12.7mm). Thus, it is considered that there was little influence of the laser irradiation on the SCC (Fig. 2); (H12003).

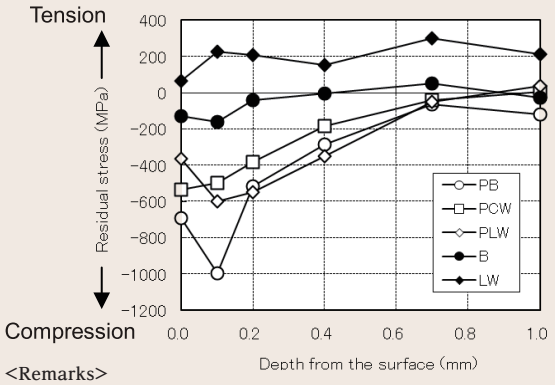
3 Proposal for the Japan Society of Mechanical Engineers standard of Concrete Cask [Non Destructive Inspection method on the weld part of the canister]

Based on results of our research on a Non-Destructive Inspection method to weld part of the canisters and the discussions of the expert committee set up in CRIEPI, we proposed a revision plan of "spent fuel storage facility construction code, JSME S F B 1-2003" to the Japan Society of Mechanical Engineers. Non-Destructive Inspection necessary for every steel grade after having classified the available materials for canisters into austenitic stainless steel and two-phase stainless steel was proposed (Table 1).

4 Development of new shock absorbing material for the transport package

We focused on rigid polyurethane foam (hereinafter "R-PUF") as a substitute material for woods used as a shock-absorbing material and built a database of the stress-strain characteristics through a compression test in which density, deformation rate and temperature are considered as parameters. Furthermore, we carried out drop tests stipulated in transport regulation using a cask of a reduced scale with shock absorbers made from R-PUF. The results of this test confirmed that R-PUF was applicable as a shock-absorbing material as the acceleration generated at the cask was less than the design value (Fig. 3); (N12020).

* A metal surface treatment which hits the surface of a device with small zirconia grains to give compressive residual stress.



<Remarks>
ZSP applied: PB (base material), PCW (weld in a circumferential direction), PLW (weld in a longitudinal direction)
ZSP not applied : B (base material), LW (weld in a longitudinal direction)

Fig. 1: Stress state improvement by the method of ZSP

Residual stress improvement was carried out on a canister with a full-scale diameter size using zirconia shot peening (ZSP) in the area close to the weld.
Tensile stress was generated in the range of 1mm depth when only grinder processing on the surface was applied after welding, but compressive stress at a depth of 0.7mm from the surface was generated by applying the residual stress improvement using ZSP and its effectiveness was confirmed.

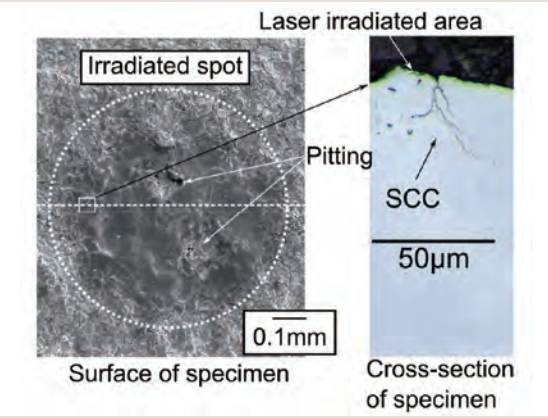


Fig. 2: Results of a corrosion test of the specimen irradiated by a laser pulse

Synthetic seawater was dropped on a specimen irradiated by a laser pulse (wavelength: 532nm, pulse width: 10ns); the specimen was set up under the environmental conditions in which SCC occurs.
As a result, cracks considered to be pitting and SCC were observed, but crack depth was extremely small. We confirmed that the laser irradiation effect on SCC propagation was negligible.

Table 1: Summary of a revision plan for a Non-Destructive Inspection method on the welds of canisters*

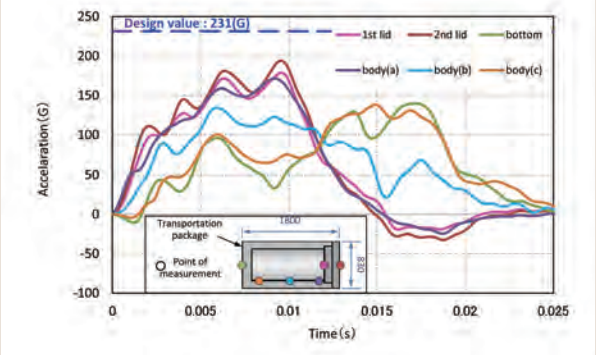
Materials	The weld crack concerned [a]	Penetration test (PT)[b]	Ultrasonic test (UT) [c]	Remarks
Austenitic stainless steels	Hot Crack	Required [d]	Not Required [e]	・An inspection interval is required every 1/4tw which is the setting grounds of the stress reduction coefficient (tw: Welding thickness) ・Text revision
Two-phase stainless steel	Cold crack	Required [d]	Required [f]	・Demand of UT for the purpose of exclusion of the cold crack due to the non-fusion part ・UT is prescribed as a new code case

a)Materials targeted for the standard are divided into two steel grades in consideration of the cracks for which there is concern about for welding and appropriate non-destructive testing is applied to each.
b)Method to detect flaws on the surface from the patterns after penetrating and wiping off an indicator applied to the surface.
c)Method to detect a defect inside the body from the reflection wave of an ultrasonic wave which was generated from a probe pressed against a weld.
d)Increase the inspection number of times than the current rule even for the same welding thickness by reducing the distance for PT.
e)The cracking which is causing concern can be detected by PT
f)UT is also required because the cracking for which there is concern might progress after the PT.

*CRIEPI proposes to Japan Society of Mechanical Engineers

Fig. 3: Accelerations at the drop test of the reduced scale model

Drop tests were carried out from a 9m height onto a rigid target using a 1/3 reduced cask with shock absorbers made of rigid polyurethane foam.
The maximum acceleration generated in the cask during the drop test was less than the design value, confirming that rigid polyurethane foam has enough performance as a shock absorbing material.



Priority Subjects — **Establishment of Optimal Risk Management**

Development of a Prediction Method for Meteorological and Climatic Impact on Power Facilities

Background and Objective

Recently, natural disasters such as floods, heavy snowfall, strong wind and gusts have occurred frequently due to sever typhoons and bomb cyclones. It is necessary to secure the safety and reliability of the electric power distribution facilities, hydraulic power plants, and harbor facilities which have been exposed to natural external forces. The first purpose of this study is to improve the accuracy of the numerical weather prediction model for assisting the maintenance and operation of electric power facilities. The second purpose is to develop and improve the regional climate model in order to predict the climate change on the Japanese region in 20 to 30 years, and to make an impact assessment of the design wind speed or precipitation for electric power facilities.

Main results

1 Development of a short-term rainfall forecasting method using a meteorological radar

Our software for analyzing radar data is updated to handle data obtained from a variety of organizations including MLIT, JMA, and electric power companies. A method is also developed to assimilate radar data into our numerical weather forecasting and analysis system (NuWFAS). We investigated its usefulness to use together with a traditional nowcasting technique that is based on extrapolation of radar data with a high performance regarding 1-hour rainfall forecasting. Consequently, this hybrid method can work well for 3-hour heavy rainfall forecasting.

2 Windstorm simulation using the CRIEPI weather forecasting and analysis system

Windstorm simulations to evaluate turbulence characteristics, especially gust wind, provide important information for the wind-resistance design of electric power distribution facilities, such as transmission lines and towers. To simulate the turbulence characteristics of a windstorm, the CRIEPI weather forecasting and analysis system, NuWFAS, has been developed by adopting a large-eddy simulation (LES) technique for the turbulence model, which allows for very high-resolution simulation with a horizontal grid spacing of 50m (the value in the existing simulations are generally 2-5km). The performance of the model was verified through windstorm simulations for an event due to the passing of a bomb cyclone; simulation has a capability to represent the wind turbulence parameters (Fig. 1), such as gust factor, of a low pressure windstorm and a typhoon.

3 Weather pattern analysis of heavy rainfall in Japan's rainy season using a neural network

In addition to the rainfall forecast for the next several days, long-term change in the characteristics of local precipitation is important for disaster prevention and preservation of hydraulic power plants. To evaluate change, a classification technique which extracts spatial patterns of anomalous weather patterns in relation to heavy rainfall events during Japan's rainy season have been developed by using a neural network algorithm, so-called "Self-Organizing Map". This method picked up six weather patterns in relation to extreme high-precipitation events around western Japan (Fig. 2) from atmospheric variables and local precipitation of the past 31 years (1979-2009). The analysis enables us to easily understand the recent change in the frequency of precipitation-related weather patterns in eight hydrological-separated regions (Fig. 2b, 2c)(V12017).

4 Estimation of impact on precipitation over drainage basins in future climate

To evaluate the change in extreme meteorological events with global warming, a statistical downscaling method has been developed which enables estimations of climates of regional scale (several km) from the coarse (100-200km) data of a global climate model. The downscaling method was applied to estimate the precipitation over 20 basins with areas of 20 km^2 to 2300 km^2 in the Kyushu region of Japan, to compare current and future precipitation, when a global mean temperature increase by 1.1 K. The result indicates that heavy precipitations with 50-year return periods increase in all drainage basins, and the average of the increase ratio is estimated to be 20% (Fig. 3) (V12016). Such a projection of change in precipitation over drainage basins is required for estimation of the damage caused by heavy precipitation/flood with global warming.

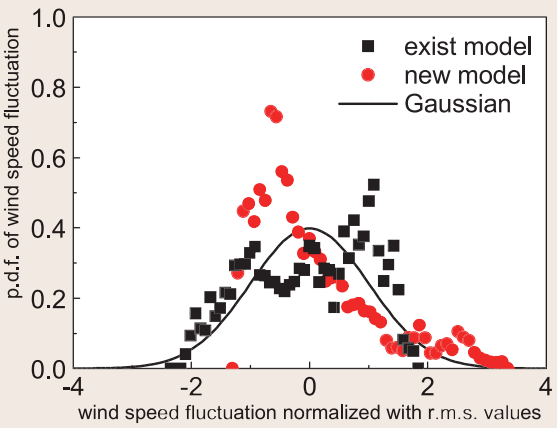


Fig. 1: Verification of turbulence simulations for windstorms with a passing bomb cyclone

The bomb cyclone, which passes through the Sea of Japan during the beginning of April 2012, yielded windstorms all over Japan; with maximum wind speeds recorded at the 75 meteorological cites. The windstorm in the Tohoku region was simulated with the existing and newly developed NuWFAS. The horizontal grid spacing was made finer with 6-nested computational domains, which achieves very high resolution grids with a spacing of 50 m. Fig. 1 shows a comparison of turbulence simulations results between existing and newly developed models. This figure depicts the probability density functions (PDF) of wind speed fluctuations normalized with r.m.s values, σ, corresponding to the gust factor. The newly developed model with LES appropriately represents the occurrence of high-speed wind. The wind speed exceeding 2σ reasonably agrees with observations, whereas the PDF with the existing model tends to be negatively skewed.

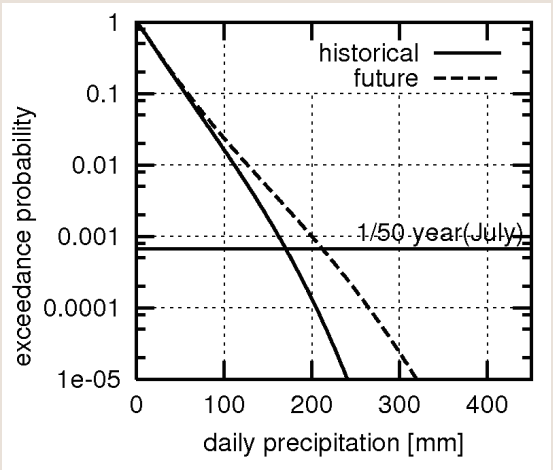
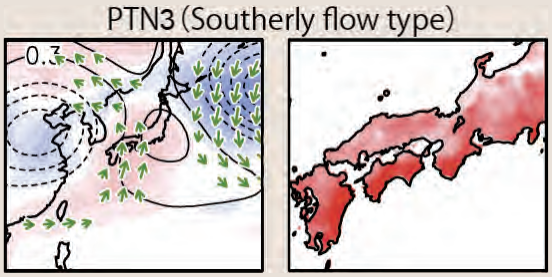


Fig. 3: Change in precipitation over a drainage basin with global warming

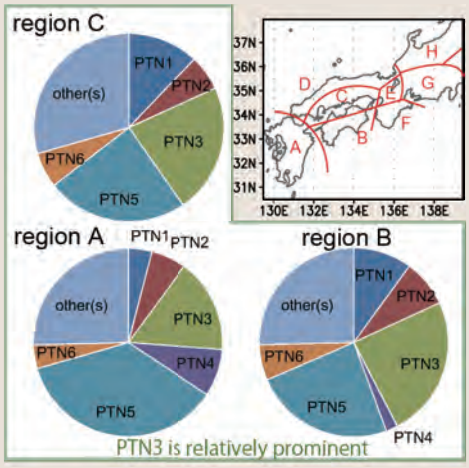
The proposed statistical downscaling model is applied to estimate climatological probability density function (PDF) of precipitation over drainage basins in the Kyushu region of Japan from the data of global warming projection by a climate model with 120-km resolution. The solid and broken lines indicate the probability of exceedance calculated from PDF under historical and future climates respectively (increase in the global annual mean temperature of 1.1K).

It is shown that such an increase in temperature will cause an increase in the probability of heavy precipitation in July over the drainage basin with an area of 491km^2. For 20 basins, the average increase ratio in precipitations with 50-year return periods is estimated at 20%.

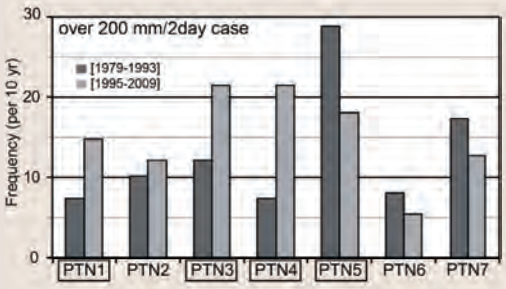


(a) One example (PTN3) of the weather patterns in relation to the extreme high-precipitation

The patterns are the differences from the climatological state of average years. (Left) Color shade exhibits 850-hPa equivalent- potential temperature, with the red shade implying relatively unstable atmospheric condition. Green vectors exhibiting 850-hPa wind are strong around the southern coast of Japan. The black line shows 200-hPa geopotential height. (Right) Color shade exhibits local precipitation pattern, with the red color implying relatively high-precipitation.



(b) Rate of the precipitation pattern frequency of the top 50 rainfall events in the region A-C.



(c) Long-term change in the frequency of precipitation-related weather patterns.

Fig. 2: Regional characteristics of the weather patterns and long-term change

We simultaneously analyzed five atmospheric variables (equivalent-potential temperature, zonal and meridional wind, geopotential height and local precipitation of western Japan) of the past 31 years (1979-2009), and picked up six weather patterns (PTN1-6) in relation to the extreme high-precipitation events (Fig. 2a). Rate of the precipitation pattern frequency in the eight regions enables us to easily understand the difference in the regional dependence between each weather pattern and heavy rainfall (Fig. 2b). Comparison of the pattern frequency between the first and second half of the past 31 years exhibits the increase in the frequency of weather patterns which relate to the heavy precipitation around Kyushu and Shikoku (Fig. 2c). Boxes in the horizontal axis exhibit statistically significant change in the patterns.

Priority Subjects — **Establishment of Optimal Risk Management**

Establishment of Protective Measure Technologies against Damages of Overhead Transmission and Distribution Facilities Caused by Wind and Snow

Background and Objective

In December 2005, severe snowstorms on the coast of the Sea of Japan caused electric power outage due to damage of overhead transmission facilities. The details of the damage are; the partial collapse of transmission towers resulting from overload of heavy snow accretion, the short circuiting of transmission lines caused by galloping*, and the failure of electrical insulators, or flashover, due to the sea salt contained in the snow. After the power outage due to snow-related damage occurred, CRIEPI began a ten-year research project from FY 2007 to 2016 on damage to overhead transmission facilities caused by severe snowstorms.

In the first phase (from FY 2007 to 2011) of this project, we constructed field observation systems for snow accretions on transmission facilities, conductor oscillation and their related atmospheric conditions and a consolidated data base system for snow-related damage and meteorological information. These systems have been operated continuously. Physical processes of snow-related damage were studied and current measures against it were examined. In the second phase (from FY 2012 to 2016), we will propose effective countermeasures against snow-related damage using practical analysis and prediction methods.

Main results

1 Continuous operation of field observation and consolidated data management systems

Field observation systems in seven sites across Japan have been continuously operated, as well as the data management system to store practical examples of snow-related damage and their meteorological conditions. Also, user-friendliness of the data management system has been improved by enhancing the graphic user interface (Fig. 1). A summary report was published, describing the results obtained from research and analysis in the first phase of the project, aiming to elucidate the physical process of snow-related damage, to improve its prediction methods, and to examine current measures against it based on field observation data (N19).

Furthermore, we have designed full-scale test facilities to be constructed in the eastern Hokkaido area (in Kushiro city) in FY 2013, with the purpose of conducting field observations on snow-related damage to overhead transmission facilities and to examine the effect of measures against it.

2 Development of a simple snow accretion model based on properties of snow particle accretion

In-situ observations of snow accretion on transmission lines are used to develop a method for estimating accretion efficiency. This method takes properties of snow particle accretion into account, together with the effects of wind velocity and countermeasures. From analyzing data sampled by a rod of conductor (N12024), an empirical equation for the density of accreted snow is also suggested, in which the density depends on both wind velocity and temperature. A snow accretion model is proposed based on the above findings, assuming the cylindrical shape of accreted snow. The mass of snow accretion is calculated quite easily by inputting meteorological variables and the direction of the span. Results of application suggest our model works better than traditional models (Fig. 3).

3 Study of the fundamental mechanism of galloping using wind tunnel tests

The large-amplitude and low-frequency galloping of transmission lines was physically simulated in a wind tunnel by employing a unique support technique using a sector model of four-bundled conductors. The applicability of an aerodynamic force model for simulating the galloping of overhead transmission lines was evaluated based on the wind tunnel test results (N12021). The mechanism and effect of a loose spacer in suppressing galloping were clarified in the wind tunnel tests using a sector model of the four-bundled conductors with and without rotatable sub-conductors having specific rigidity (Fig. 4) (N12022).

* Self-excited oscillation of conductors due to wind and accreted snow or ice. If the amplitude becomes large or the oscillation continues, the phenomenon may cause short circuits or facility failures through fatigue.

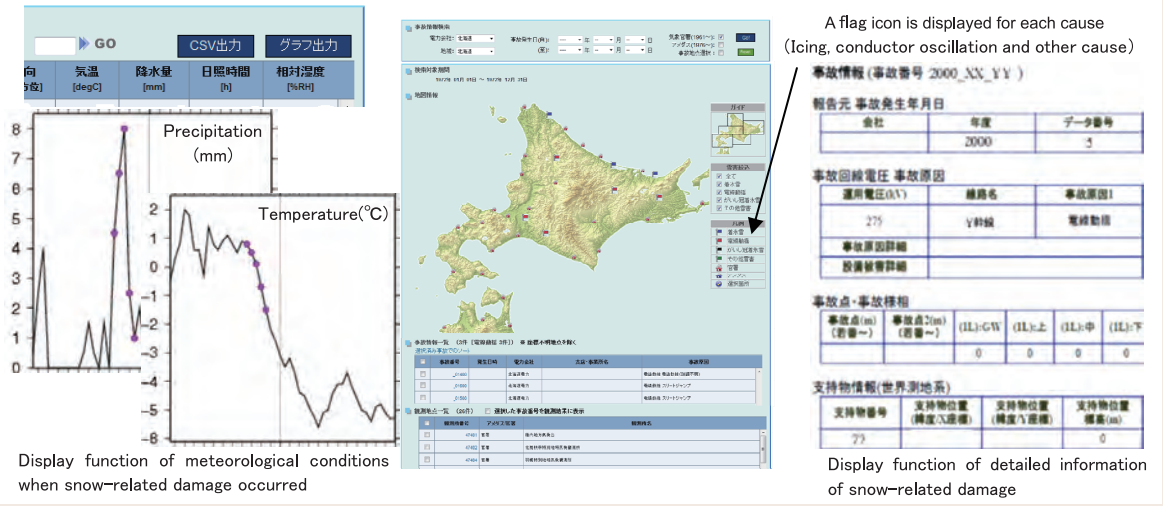


Fig. 1: Sample display windows of the improved database system for damage to overhead transmission facilities due to snow storms and its related meteorological information (Dummy data are displayed on the map.)

Data was not easy to search and analyze efficiently in the data management system before improvements were made. This is due to the fact that the data could be extracted only in text format. In order to improve user-friendliness, the GUI was reformed so that the database can be operated visually by adding a new function of displaying locations of facilities which have suffered snow-related damage and meteorological observation stations on geographical maps.

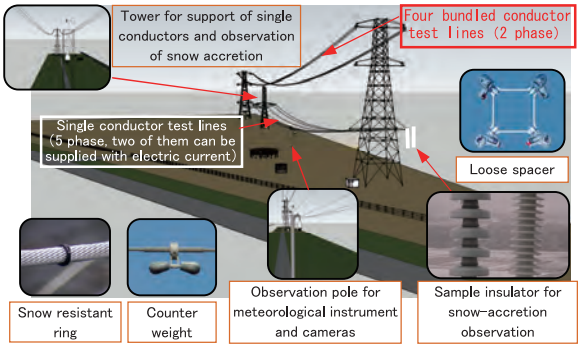


Fig. 2: Full-scale test facilities for snow-storm damage to overhead transmission lines

Field observation under actual conditions is essential for the study of snow-related damage to overhead transmission facilities and examination measures against it. A decision to construct full scale test lines was made by our institute, and a detailed plan for the test lines was designed, composed of 2 towers approx. 50m in height, a tower approx. 30m in height, 2 phases of four-bundled conductors approx. 400m in span length and 5 phases of single conductor approx. 250m in span length. Details of the field observation to be performed are as follows: measurement of fundamental meteorological conditions (wind, temperature, humidity etc.), conductor tension, and observation of snow accretion and conductor oscillation (displacement measurement by image analysis technology). A displacement sensor using GPS, video disdrometer and ultra high sensitive camera will also be used.

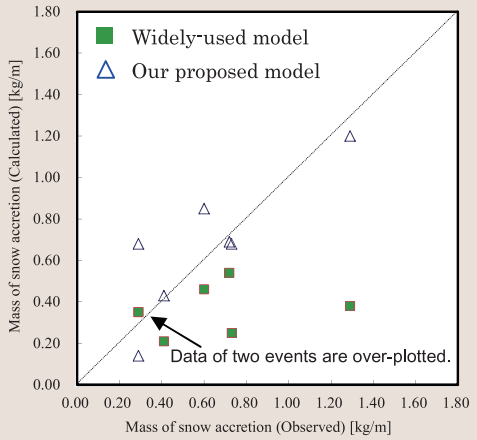


Fig. 3: Calculated and observed mass of snow accretion (applied to 7 events observed at C-line of Hokuriku Electric Power Co.)

Based on our discrimination chart for determination of the type of snow accretion, the accretion efficiency and the density of accreted snow are estimated both for wet and dry snow using meteorological data (temperature, wind velocity, and wind direction). This results in improving the quantitative accuracy and the feasibility of our model. Moreover, the combined use of our model with a meteorological model enables us to analyze and forecast the spatial distribution of snow accretion with fine resolutions.

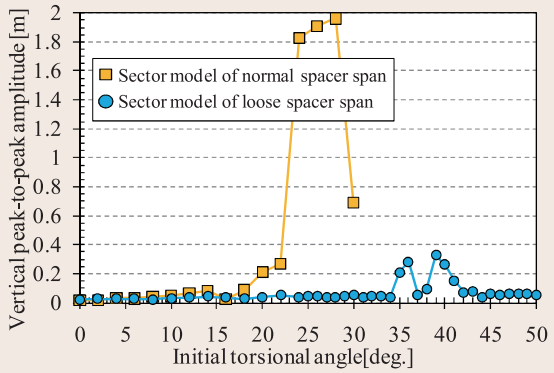


Fig. 4: Galloping suppression effect of loose spacer (results of wind tunnel test, characteristics of vertical peak-to-peak amplitude)

This figure shows an example of the test results obtained for different torsional angles of a sector model of four-bundled conductors with or without rotatable sub-conductors at the same wind speed. When two rotatable sub-conductors were set at the upwind side in the same manner as an actual span with loose spacers, the response amplitude was smaller than that in the case with four rigid sub-conductors as the normal spacer span. Furthermore, the initial torsional angle range where galloping occurred increased when the rotatable sub-conductors were installed.

Priority Subjects — **Establishment of Optimal Risk Management**

Development of Lightning Risk Management Schemes

Background and Objective

We have carried out studies of lightning protection design for transmission lines, substations and distribution systems and established lightning protection schemes for these apparatuses. However, introduction of ICT (Information and Communication Technology) in power systems such as smart meters and capacity of renewable energy sources such as wind power and solar power will increase in the future. Therefore, lightning protection methods for these facilities are required in addition to those for conventional power apparatuses.
In this project, we will develop a lightning risk assessment procedure for various power apparatuses and establish lightning protection guidelines for facilities using ICT considering the electro-magnetic immunity. We will then utilize these lightning protection guidelines for the rational lightning protection design of power systems.

Main results

1 Development of a lightning risk assessment program for distribution lines considering regional characteristics

We have added the following two functions to the previously developed lightning outage prediction program in order to assess the lightning risk of power distribution lines;
1) Evaluation of the difference between lightning current characteristics in summer and those in winter.
2) Evaluation of the ratio of burn-out outages of arresters.
The new program reproduces actual field experiences such that the number of flashovers of insulators is larger in summer and the number of burn-out outages of arresters is larger in winter. It enables us to predict outage features of distribution lines accurately.
We have also developed a lightning risk assessment program which quantitatively evaluates outage ratio of distribution lines taking the regional difference of protection measures into consideration based on the data of regional densities of distribution lines and lightning (Fig. 1). (H12010)

2 Investigation of characteristics of lightning strikes to extremely high structures

We have developed a unique lightning current measuring system that consists of two Rogowski coils for high frequencies and low frequencies to clarify the relationship between characteristics of lightning strikes to high structures and damage by lightning.
We have confirmed from impulse current tests of these coils that it is possible to observe lightning current waveforms for a wide frequency range. We have installed the coils on TOKYO SKYTREE at a height of 497m and started current observation from March, 2012. We have obtained current waveforms of 9 flashes in the fiscal year of 2012 (Fig. 2). We will use these data for the analysis of transient electro-magnetic fields inside the structures and overvoltages on the low-voltage circuits such as communication and control circuits.

3 Observation of radiation fields by lightning strikes

We have installed antennas at Maebashi, Abiko and Yokosuka to observe radiated electromagnetic fields generated by lightning strikes in an attempt to improve the accuracy of lightning location systems. The observation system enables the synchronized observation of lightning currents at TOKYO SKYTREE and radiated fields. We will use the obtained data to evaluate the accuracy of locations and currents estimated by lightning location systems, investigation of the estimation errors and development of a novel lightning location algorism.

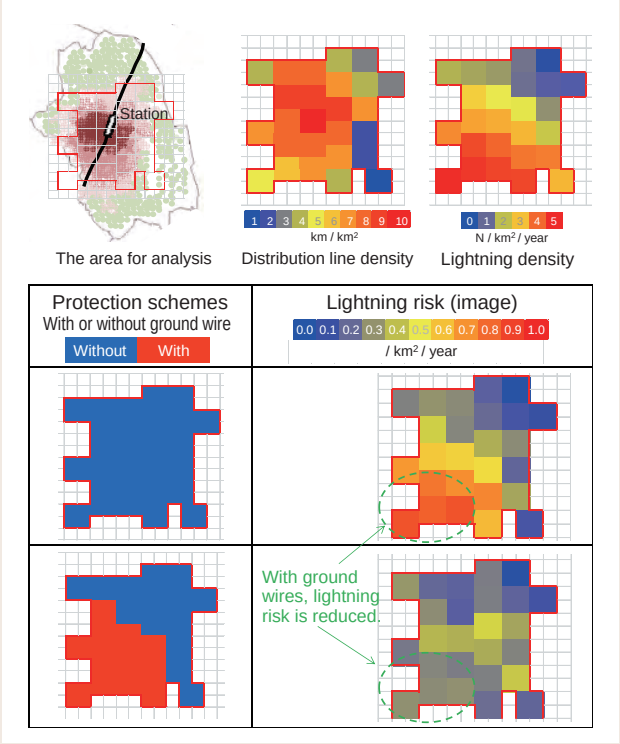


Fig. 1: Difference of lightning risks of high-voltage distribution lines with different lightning protection schemes

Lightning risk is evaluated considering regional distribution line density, lightning density and lightning protection schemes. In the case of a non-uniform lightning protection scheme, high risk areas are reduced (bottom right) compared with that of a uniform lightning protection scheme (top right).

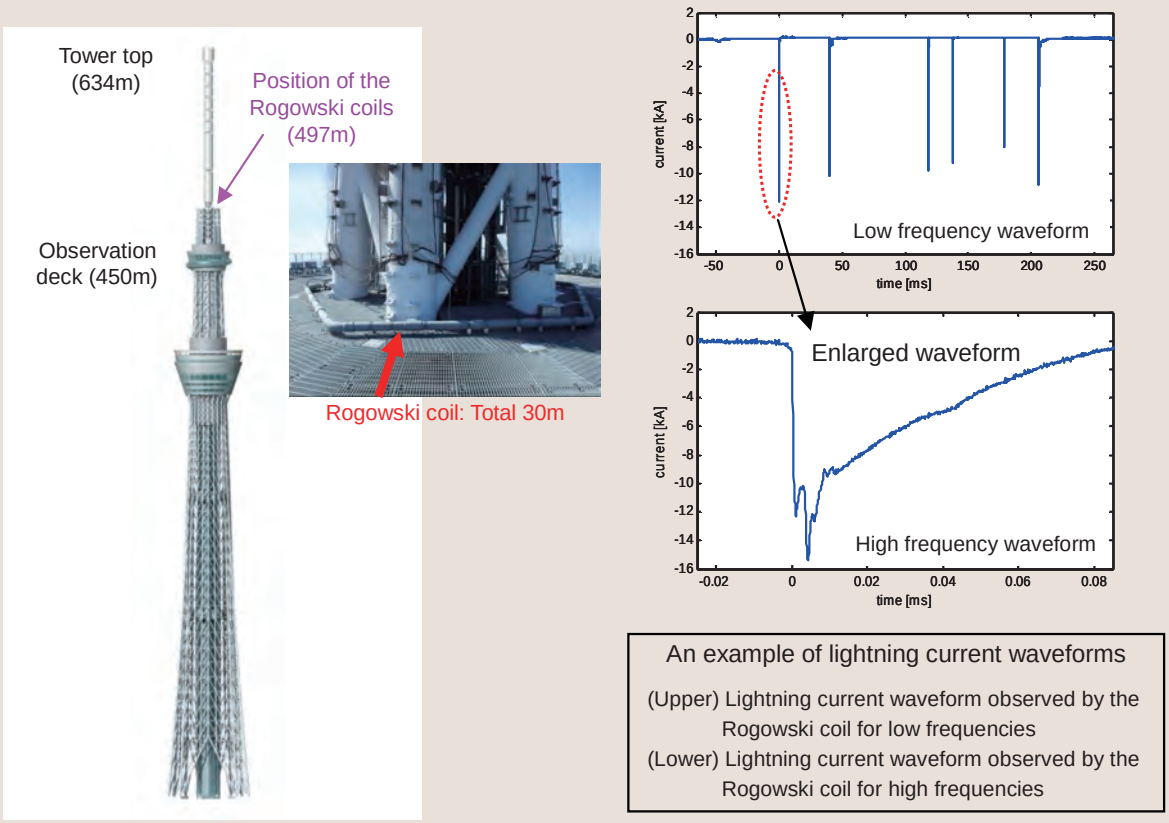


Fig. 2: Lightning current observation system installed on the TOKYO SKYTREE and an example of observed lightning current waveforms

Two Rogowski coils for high frequencies and low frequencies are installed on the TOKYO SKYTREE at a height of 497m. Measured signals are transmitted to a recording system in the observation room of the tower via optical fibers. An example of observed waveforms is shown on the right side. This is a negative lightning consisting of 6 strokes. The steep wavefront is also precisely observed.

Priority Subjects — **Further Improvement of Facility Operations and Maintenance Technologies**

Integrity Assessment of Aged LWRs

Background and Objective

For the long term operation (LTO) of LWRs, it is necessary to evaluate the safety and integrity of materials and components based on scientific knowledge. Meanwhile, in order to conduct research in the name of LTO, basic experimental or evaluation methods are also required. We will elucidate the degradation mechanism of reactor pressure vessels, core internals, piping and insulation cables for safe LTO by improving evaluation methods, experimental techniques and facilities.

Main results

1 Improvement of prediction accuracy for irradiation embrittlement and environmental degradation of RPV steels

Through the observation of surveillance specimens exposed to relatively higher fluence, it was ascertained that neutron irradiation embrittlement due to unpredictable factors did not appear in the higher fluence region. The irradiation embrittlement correlation in the present code has been revised based on the analysis of the latest surveillance data, which led to improvement of the prediction accuracy (Fig. 1) (Q12007). Round robin tests have been conducted among a national university, industries, and an institute. The tests reveal the validity of the fracture toughness test using miniaturized CT specimens, which can be taken from examined half pieces of surveillance Charpy specimens.

2 Evaluation of the wall thinning profile caused by flow accelerated corrosion in separation and union pipes

In some parts of T-tubes with reinforcing plate or T-joints which have curvature at their junctions (crotch), it is difficult to accurately evaluate wall thinning profiles due to configurative restraints. For such pipe elements, by conducting flow analysis, the mass transfer coefficient which is related to flow accelerated corrosion (FAC) was calculated in order to evaluate wall thinning profiles and relative thinning rate. An obvious wall thinning tendency is recognized beneath the reinforcing plate of T-tube and at crotch of T-joint (Fig. 2). Although the wall thinning profile can be obtained adequately by measuring the current locations, a more detailed wall thinning profile can be evaluated by the flow analysis.

3 Improvement of prediction accuracy for wall thinning

The effect of dissolved oxygen concentration on FAC rate was evaluated. FAC of the carbon steel at 180°C is suppressed in neutral water (pH 7.0) containing more than 25 to 30 ppb oxygen or, in alkaline solution (pH 9.8) containing more than 1 to 4 ppb oxygen. It is demonstrated that the increase in pH decreased the dissolved oxygen concentration necessary for FAC suppression (Fig. 3). Considering the effect of oxygen concentration, our FAC prediction model is improved. (Q12008)

4 Development of a prediction model for the degradation of cable insulation

A new degradation model for polymeric insulations used in safety-related cables was developed in order to account for the effect of antioxidants and to simulate several synergisms in various thermal and radiation environments. A chemical reaction scheme was used to represent oxidation reactions via the decomposition of peroxide radicals. The calculation result confirms that the new one-dimensional model qualitatively fits an aging depth profile of thermally-aged polyethylene. High activation energy was applied to the initiation reaction in order to simulate the dose rate dependencies of material lifetimes at several fictitious temperatures (Fig. 4). The contribution of heating to material degradation gradually becomes dominant with increasing temperature. Non-Arrhenius behavior is also successfully demonstrated with reasonable apparent activation energy for the terminal product generation.

Other reports: (Q10035), (Q10016)

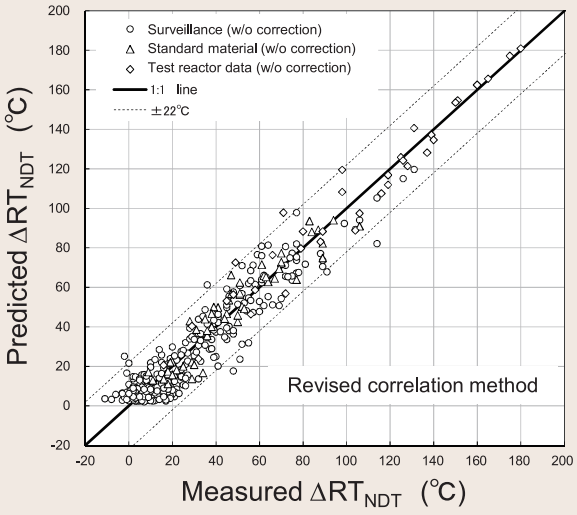


Fig. 1: Comparison of the predictions using the revised correlation method with the measurements of the surveillance program

The prediction accuracy has been improved through the large embrittlement region including high fluence surveillance data as well as test reactor irradiation data.

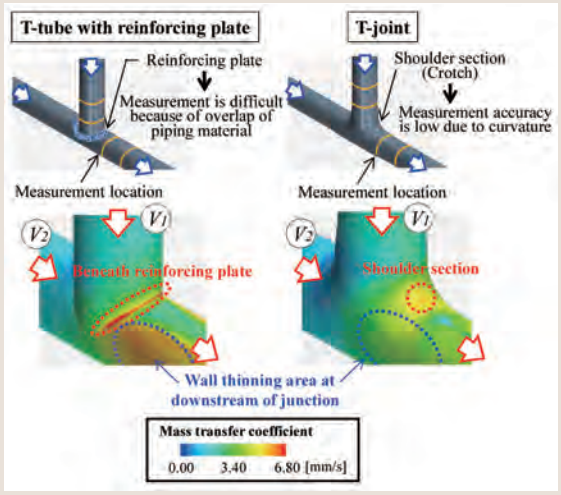


Fig. 2: Wall thinning profile of T-tube with reinforcing plate and T-joint

In some parts of T-tube with reinforcing plate or T-joint which has curvature at the junction, it is difficult to accurately evaluate wall thinning due to their configurative restraints. Mass transfer coefficient, flow factor of FAC, was calculated and wall thinning profiles of the T-tube or T-joint were evaluated, by conducting flow analysis. Apparent wall thinning is recognized where actual measurement is difficult (red dotted line). The wall thinning is also recognized at downstream of junction (blue dotted line), where wall thickness can be measured.

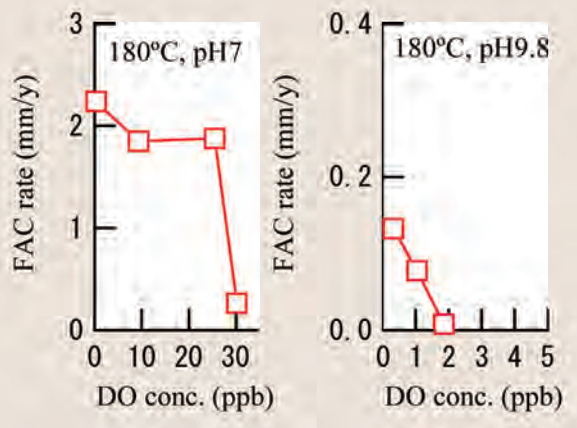


Fig. 3: Effect of dissolved oxygen (DO) concentration on the FAC rate

Specimen: Carbon steel (0.001wt% of Cr). Temperature: 180°C. Flow rate: 3.8 to 5.1 m/s. NH_3 was injected to control pH of the solution.
The effect of dissolved oxygen concentration on the FAC rate was evaluated. FAC of carbon steel at 180°C was suppressed by the oxygen more than 25 to 30 ppb in neutral water (pH 7.0), and was suppressed more than 1 to 4 ppb in alkaline solution (pH 9.8).

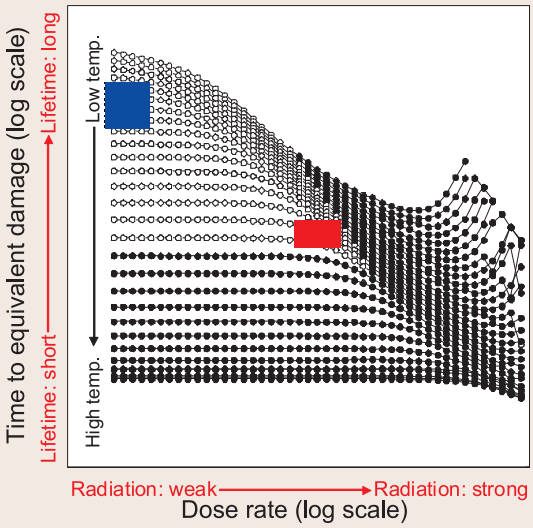


Fig. 4: Relationship between time to equivalent damage (TED) and the dose rate

Areas painted in red and blue represent the simulated conditions of accelerated aging and actual operation, respectively. Open symbols indicate that the distribution of oxidative degradation in the bulk at TED is homogeneous, while the solid symbols represent inhomogeneous distribution. The U-shaped dose rate dependencies descend to lower value with increasing temperature.

Priority Subjects — **Further Improvement of Facility Operations and Maintenance Technologies**

Development of Life Assessment Technology for High Temperature Structural Components of High Chromium Steels

Background and Objective

Ultra-supercritical (USC) pressure thermal power plants supply power with high efficiency and large capacity. However, trouble caused by creep damage has occurred in various types of welded joints in the large-diameter high chromium steel pipes used in such plants. Such trouble adversely affects the stable operation of USC thermal power plants. The establishment of highly reliable diagnostic technologies for high-temperature equipment made of high-Cr steels is required as a preventive measure.

In this project, we aim to develop diagnostic techniques for assessing creep damage in girth welded and nozzle stub welded portions of the high-Cr steel pipes, which are vulnerable to creep damage, and to apply the technologies to the on-site maintenance and operation of facilities.

Main results

1 Formulating equations for evaluating the creep rupture life of welded joints

A number of data obtained by creep tests on small welded joint specimens made of typical high-Cr steels were analyzed by The Assessment Committee on Creep Data of High Chromium Steels, whose members are from all electric utilities that operate thermal power plants, plant and steel manufacturers, and research institutions. The equation for evaluating the creep rupture life formulated in FY2005 was also reviewed (Fig. 1).[1] The equation revised using the latest data and knowledge enables the long-term creep rupture life for welded joint materials to be evaluated with higher reliability than was previously possible. The validity of the revised equation has been accepted by the committee on Review on Reliability of High Temperature Strength Enhanced Ferritic Steels for Fitness-for-Service of Thermal Power Components, established by the Ministry of Economy, Trade and Industry, and is currently used in the management of operating USC plants.

2 Assessment of applicability of equations for evaluating the creep rupture life of girth welded portions

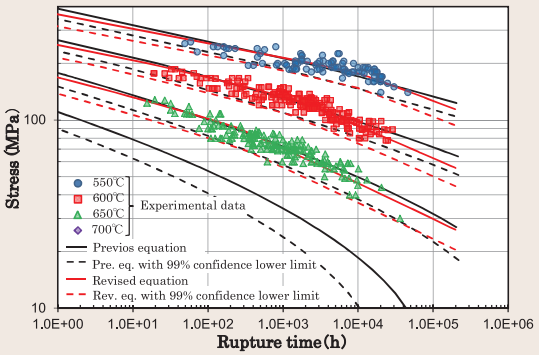
Girth welding is essential for connecting pipes in power stations. In assessing the creep rupture life of girth weld zones, axial stress should be appropriately considered. To achieve this, creep tests were carried out under conditions where a mechanical load for generating axial stress and an internal pressure were superimposed. Specimens were small cylinders equivalent to boiler tubes and large-diameter pipes with the dimensions of real piping (outer diameter, ≈700 mm). All specimens were made of 12Cr steel and had girth weld zones. Test results indicated that the revised equation estimates creep rupture lives shorter compared with experimental ones in the region where the contribution of axial stress is large (Fig. 2).

3 Assessment of the effect of welding conditions on creep strength

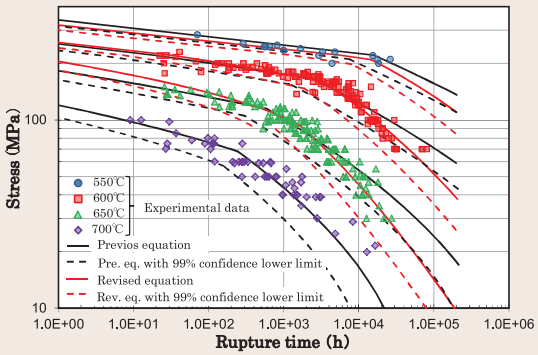
A uniaxial creep test was performed using a 9Cr steel joint specimen with a diagonal groove, which is frequently adopted in on-site welding. The creep rupture life of this specimen was approximately 60% that of a 9Cr steel joint specimen with a narrow groove, which is frequently adopted in shop welding (Fig. 3). Another uniaxial creep test was carried out using a specimen prepared by following the temperature history in the heat-affected zones of a material subjected to multilayer welding to clarify the mechanism underlying type IV cracking*1 and to assess the weld zone subjected to multiple welding passes. From the test results, the relationship between the temperature history and creep deformation characteristics was examined. The creep deformation characteristics strongly depended on the temperature history; a creep deformation rate of up to approximately 1000 times higher than that of the base metal was observed when the specimen was heated to around the transformation temperature range*2 of the microstructure. Thus, the quantitative information necessary to analyze the effect of the thermal history during welding on the strength of a material was obtained (Fig. 4).

*1 Pattern of an internal crack propagating in the fine-grain region of a welded heat-affected zone.
*2 Temperature range in which a crystal structure transforms from a body-centered cubic lattice to a face-centered cubic lattice. For high-Cr steels, the transformation temperature range is approximately 810-930°C.

References: [1] M.Yaguchi, T. Matsumura and K. Hoshino, Proc. of ASME PVP2012 Conf., PVP2012-78393, 2012.



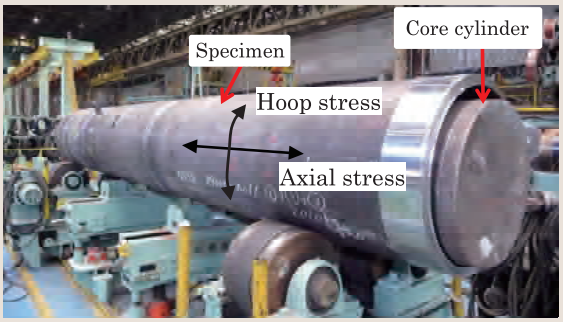
(1) 9Cr steel welded joint



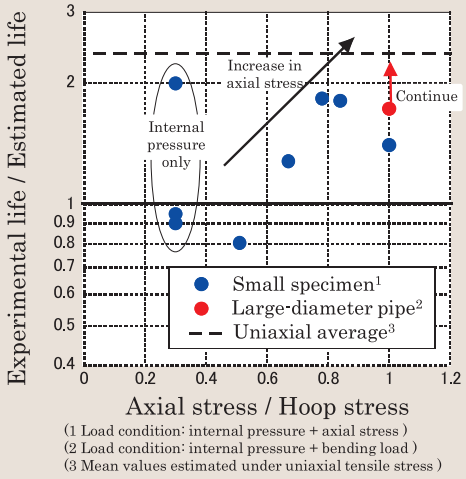
(2) 12Cr steel welded joint

Fig. 1: Creep data and creep curves obtained using equations for evaluating creep rupture life

Compared with previous equations, the equations revised using the latest data and knowledge estimate a shorter life for welded joints of the high chromium steels at 600°C, which is close to the temperatures of actual plants. Hence, the new equation has made it possible to estimate the critical rupture life of large-diameter high-Cr steel pipes with higher reliability than previously possible.



(1) Large-diameter pipe with dimensions of actual equipment (before test)

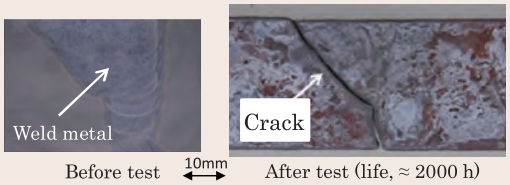


(1 Load condition: internal pressure + axial stress)
(2 Load condition: internal pressure + bending load)
(3 Mean values estimated under uniaxial tensile stress)

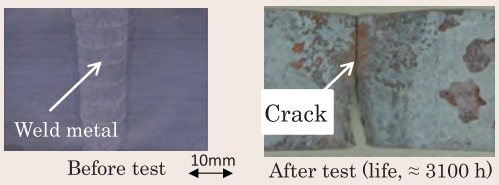
(2) Estimated creep rupture life of 12Cr steel girth joints

Fig. 2: Assessment of creep rupture life of girth welded portions

The demonstration test facility on structural integrity, BIPress, developed in our institute was used in a creep test on large-diameter pipes with the dimensions of an actual piping system. In the region of high axial stress, which may cause creep damage to girth welds, the revised equation tended to provide conservative estimation of creep life.



(1) 9Cr steel welded joint with diagonal groove



(2) 9Cr steel welded joint with narrow groove

Fig. 3: Effect of groove shape on creep rupture life (temperature, 650℃; stress, 60MPa)

Results indicate that welding conditions (particularly the groove angle) significantly affect the creep rupture life.

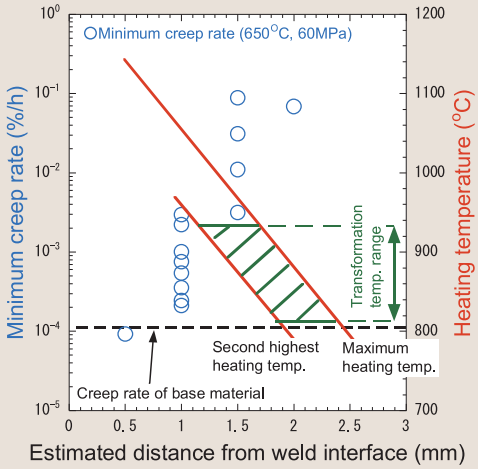


Fig. 4: Relationship between temperature history and creep rate

The creep deformation rate sharply increased when the peak heating temperatures during welding were in the transformation temperature range.

Priority Subjects — **Further Improvement of Facility Operations and Maintenance Technologies**

Development of Techniques for Comprehensive Impact Assessment of Thermal Power on Atmospheric Environment

Background and Objective

The importance of thermal power generation is increasing in Japan due to long-term shutdown of most nuclear power plants, and the renewal of old facilities as well as ongoing operation of existing thermal power plants are required for the stable supply of electricity. The Japanese government recognizes that the environmental impact assessment may be simplified under certain conditions in order to encourage the swift renewal and new/additional construction of thermal power plants. On the other hand, the effect of fine particulate matter ($PM_{2.5}$) and photochemical oxidant (Ox), which are major secondary air pollutants, on atmospheric environment should be estimated for successive operation of plants.

In this project, we aim to develop software tools for making atmospheric environmental impact assessments easier, quicker and less expensive, and also to contribute to the establishment of rational control measures through development of assessment methods for secondary air pollution.

Main results

1 Development of software tools to support atmospheric environmental impact assessments of thermal power generation

We have developed a prototype software tool to support atmospheric environmental impact assessments of replacements and new/additional construction of thermal power plants. The tool, coupled with the Geophysical Information System (GIS), allows computing dispersion and drawing contour maps of exhaust gas calculated from inputs of time and source conditions including location, stack height, and gas specifications (Fig. 1). Monitored atmospheric concentration data are automatically drawn on the map and summarized in a table in order to compare the source contributed concentrations. In the fiscal year of 2013, we will add functions such as dispersion simulations of multiple sources and self-judgment of meteorological and topographical conditions for downdraft, downwash and fumigation.

2 Establishment of an atmospheric monitoring system for secondary air pollution assessment

We have been developing an air quality model, a numerical model that accounts for detailed processes of emission, transport and chemical reactions of pollutants in order to assess the secondary air pollution. A particulate carbon monitor was added to our atmospheric monitoring system in Komae, Tokyo, to obtain monitoring data of $PM_{2.5}$ major components throughout of years for validation of the air quality model. Surface concentrations are related to upper-air concentrations. We established an observatory at an elevated site on the Tokyo Skytree to obtain urban upper-air quality (Fig. 2).

3 Improvement of modeling of $PM_{2.5}$*

Present air quality models seem to predict observed $PM_{2.5}$ mass concentrations well. However, the models considerably overestimate nitrate and underestimate organics concentrations among major components of $PM_{2.5}$. It is necessary to remediate these discrepancies for the establishment of adequate controls based on source apportionment estimates. We improved model predictions of nitrate concentrations by considering model configuration and conditions and changing temporal profiles of emissions to adjust discrepancies. The organics concentration was also revised. These findings may be useful in the estimation of impacts of thermal power on secondary air pollution.

* This work was performed as contract research with the Ministry of the Environment (the Environment Research and Technology Development Fund C-1001).

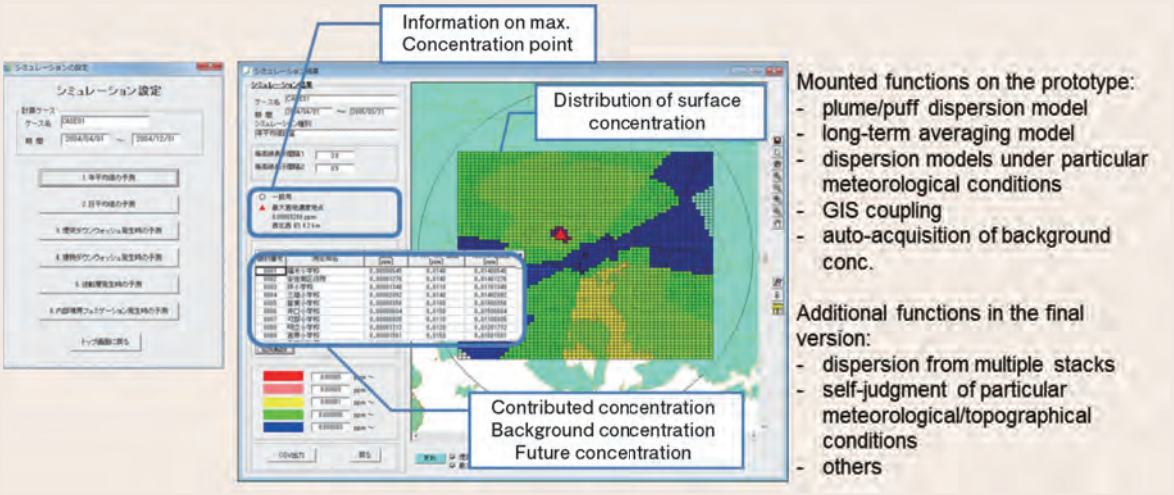


Fig. 1: A Screenshot of the prototype of the atmospheric environmental impact assessment support tool

In the right window panel, provide source information and computational period in the left column and, then, the source point (red triangle) is shown on a map (light aqua: land; white: sea). Select a dispersion scheme in the left window panel and, then, calculated concentrations are drawn with filled colors given in the legend box on the map in the right window panel. The table summarizes source-contributed, background and future concentrations at given locations.

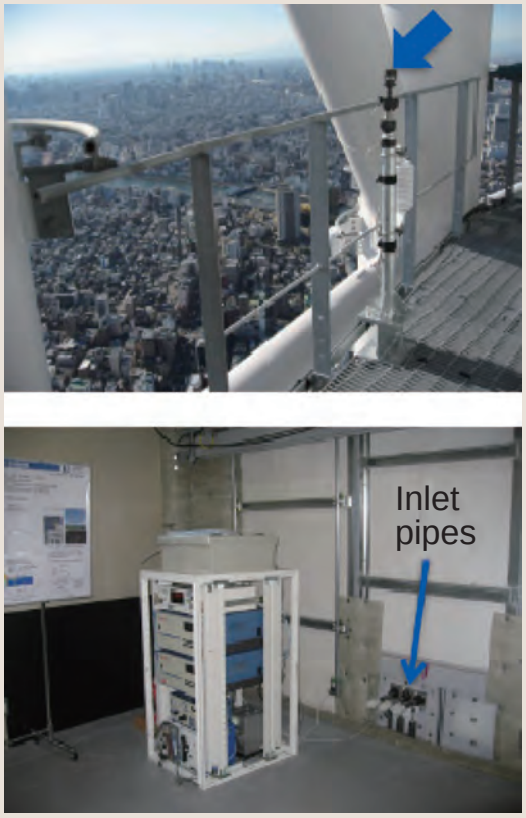


Fig. 2: Urban upper air quality monitoring station

Meteorological monitors outside (upper picture) and air quality monitors inside (lower picture) the Tokyo Skytree. Rare data regarding air quality over a megacity are accumulated for use in the development of a secondary air pollution evaluation method.

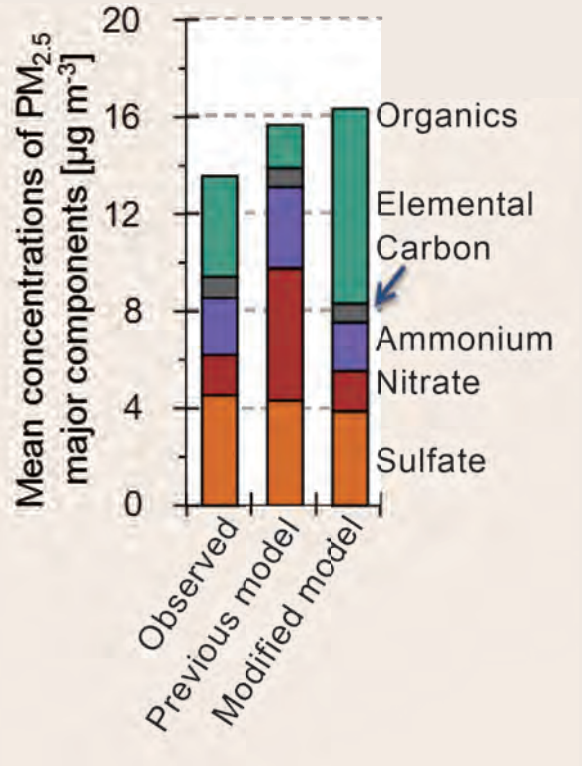


Fig. 3: Comparison of observed $PM_{2.5}$ components with calculated results of previous and modified models

The previous model (center column) overestimates the nitrate concentration and underestimates the organic concentration. The modified model gives much better results. Further studies are necessary for better performance on the organics.

Priority Subjects — **Further Improvement of Facility Operations and Maintenance Technologies**

Development of Technologies for Supporting Construction and Maintenance of Power Plants from the Viewpoint of Biodiversity Conservation

Background and Objective

According to the Environmental Impact Assessment (EIA) Law amended in 2011, an assessment of biodiversity must be conducted at the planning stage of a project and results of conservation measures must be published. In addition, wind-power generation has become subject to the EIA Law. The necessity of biodiversity offsets*1 and assessment of the environmental impact of power plants on marine ecosystems has started to be discussed at government level, increasing the necessity of technological developments related to the further introduction of regulations and systems. The target of this research is to develop technologies related to biodiversity assessment and conservation to help enable the smooth construction, renewal, and operation of power plants.

Main results

1 Development of an assessment method for important species*2 used in the environmental impact statement at the planning stage

In the amended EIA Law, the impact assessment on important species must be conducted at the planning stage. We analyzed the habitat of important species recorded in past environmental assessment reports and developed a method estimating the probabilities of occurrence of those species in the planned project areas using published vegetation information (Fig. 1). Using this method, it is possible to estimate the distribution of important species from vegetation maps without additional surveys, even in the project areas where little species information has been published.

2 Development of an efficient survey technique for flying birds

The impact of wind-power generating facilities on birds should be predicted and assessed as a part of EIA as the collision of birds with wind-power generating facilities is a concern. To obtain data required for the impact assessment, flying birds have been visually observed; however, this requires considerable effort and the error is large. We developed a system for monitoring flying birds with the purpose of establishing an efficient and high-precision survey method (Fig. 2). In this system, several time-sync cameras continuously monitor flying birds to automatically record their images. We also developed software for detecting flying objects (Fig. 3) to extract only the flight path of flying birds from the recorded images. The system combined with the software enables the flight path of flying birds to be drawn automatically and the total number of flights to be counted from the images without the need for manual work. The future goal is to develop software for obtaining the flight path of birds three-dimensionally using recorded images in order to further facilitate the survey of flying birds.

3 Development of a habitat assessment method for mitigation measures

We have been conducting studies on habitat assessment using genetic indicators to improve the effectiveness of mitigation measures, such as the transfer and transplantation of important animals and plants from the project areas to alternative areas. The Japanese brown frog, one of the important species in the EIA, was used as an example. Genetic analysis was carried out using the DNA collected from the eggs from different populations of Japanese brown frogs located at various sites, and quantitatively evaluated the connectivity among multiple populations. This technique may enable identification of optimum habitat conditions and priority habitats for conservation (Fig. 4).

*1 "Biodiversity offsets" refer to mitigation measures such as a creation of equivalent habitats outside a project area when the negative impact to habitats at the project area cannot be avoided or fully compensated.
*2 "Important species" refer to the species designated by laws and regulations by the government and municipalities as being critically endangered or vulnerable to environmental changes.

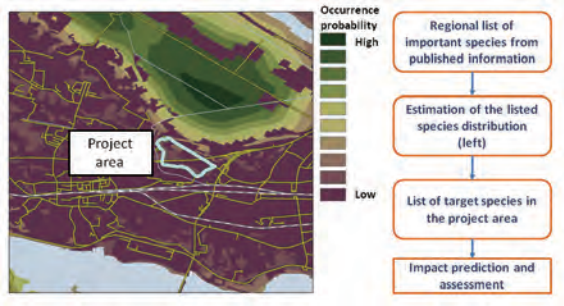


Fig. 1: Estimation of the distribution of important species at the planning stage

The estimated distribution of important species, which should be assessed at the planning stage, can be mapped in and around the project area (left). From the published information which suggests the existence of many important species in the whole region, the list of target species for the estimated distributions of those species in the project areas is extracted. This enables efficient impact assessment of power plants at the planning stage (flowchart, right).

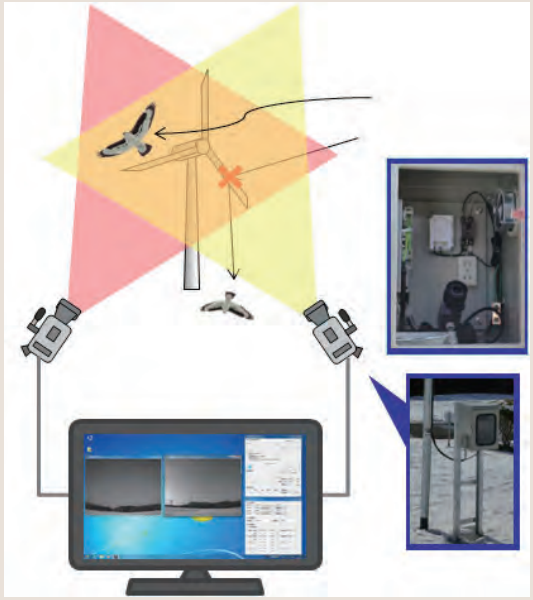


Fig. 2: Outline of the system for monitoring flying birds

A system was developed in which up to four time-sync cameras monitor flying birds to automatically record their images. The future goal is to develop software for obtaining the flight path of flying birds three-dimensionally using the recorded images from several cameras and to develop a system to easily determine the position and altitude of flying birds required for wind power assessment.

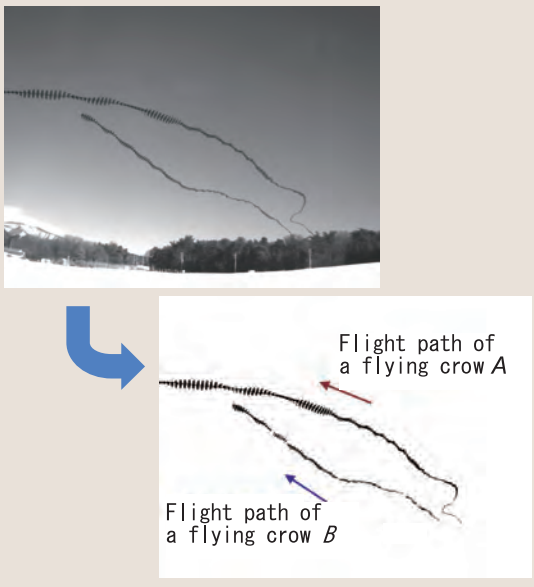


Fig. 3: Flight path of flying crows extracted using software

Using the software for detecting flying objects, the flight path of flying birds recorded for a certain period of time can be extracted to automatically draw the flight path of birds on a single image (the upper figure indicates an example of the flight path of two crows). The monitoring system for flying birds and the software enable us to draw the flight path of flying birds automatically and count the total number of flights in the entire recorded image.

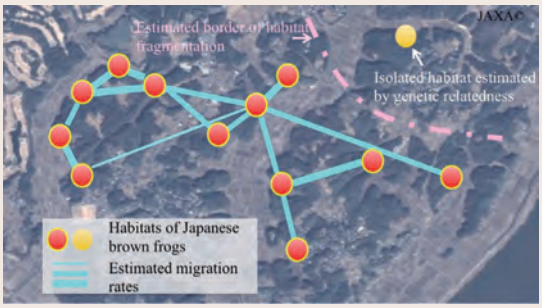


Fig. 4: Habitat assessment by genetic analysis

Genetic analysis was carried out using approximately 260 samples collected from 13 habitats. Connectivity among multiple habitats such as immigration and emigration rates of individuals was estimated qualitatively, based on genetic relatedness among habitats. Isolated habitats (upper right) and principle source habitats can be identified. The result may enable further development of effective conservation measures.

Priority Subjects — **Further Improvement of Facility Operations and Maintenance Technologies**

Synthesis System of Numerical Analysis for the Currents and Sediments in Rivers and Reservoirs

Background and Objective

The proper maintenance and operation of hydropower facilities owned by electric power companies are important in terms of providing a stable electric power supply and the utilization of renewable energy. In recent years, forests adjacent to rivers and reservoirs are remarkable, and the preservation of facility environments including sediment management has become an important subject. In this project, the total management of watershed-sedimentation techniques that estimate the points/places of sediment yield in dam basins and that observes the behavior of sedimentation and turbidity in rivers and reservoirs will be enacted, along with a synthesis system of numerical analysis that predicts sediment level and turbidity.

Main results

1 A development of evaluation methods for soil runoff from upstream and slope stability

A method to evaluate rainfall infiltration and slope stability of ground (Fig. 1) was developed to estimate the amount of soil runoff when a landslide is caused by heavy rain, which has been seen frequently in recent years. A result of the application of this method to a slope field in a typhoon passage showed that the increase of rainfall caused a rise in saturation and decrease of the local safety factor of the ground (N12014). This method will be applied to a slope with past slope failure to calculate the critical cumulative rainfall for slope maintenance and to estimate the soil runoff in the slope failure caused by heavy rain.

2 Construction of a system for measuring sediments transportation in rivers and reservoirs in real time

In order to increase the practicality of numerical model analysis for predicting the sedimentation and scouring in rivers and turbidity behavior after sediments have begun flowing from a dam, the behavior of sediment in rivers and reservoirs was measured, and the data was used for verification purposes. In addition to the mobile flow and sedimentation measurement devices constructed to date for measuring the flow velocity and height of river beds, in 2012 instruments capable of determining turbidity, water quality, and other factors from the dynamic state of sediment in a river were installed at 7 locations from a hydropower dam to a river mouth, and experimental operation commenced (Fig. 2). During the passage of a typhoon in September 2012, data were collected on turbidity and water quality and were analyzed to determine the relationships between the increase or decrease in flow rate and the turbidity and water quality. The composition of the suspended matter at each location was analyzed (Fig. 3).

3 Development of an integrated system for predicting and estimating rainfall intensity, discharge, river flow, water quality, sediment transport and deposition

We will develop a new integrated system, which includes methods for predicting and estimating rainfall intensity, discharge, river flow, water quality, sediment transport and deposition, in order to plan and judge an operation of a sediment pass-through on hydropower dam reservoirs. In 2012, we combined a new prediction model for the water level of reservoirs, which estimates operational routing of the hydropower intake rate, the dam spillway discharge and the reservoir volume, with a prediction model of rainfall intensity and discharge (NuWFAS and HYDREEMS) in order to estimate the effect of water level on the sediment pass-through. Furthermore, resolution satellite remote sensing data was applied to estimate the potential sediment production.

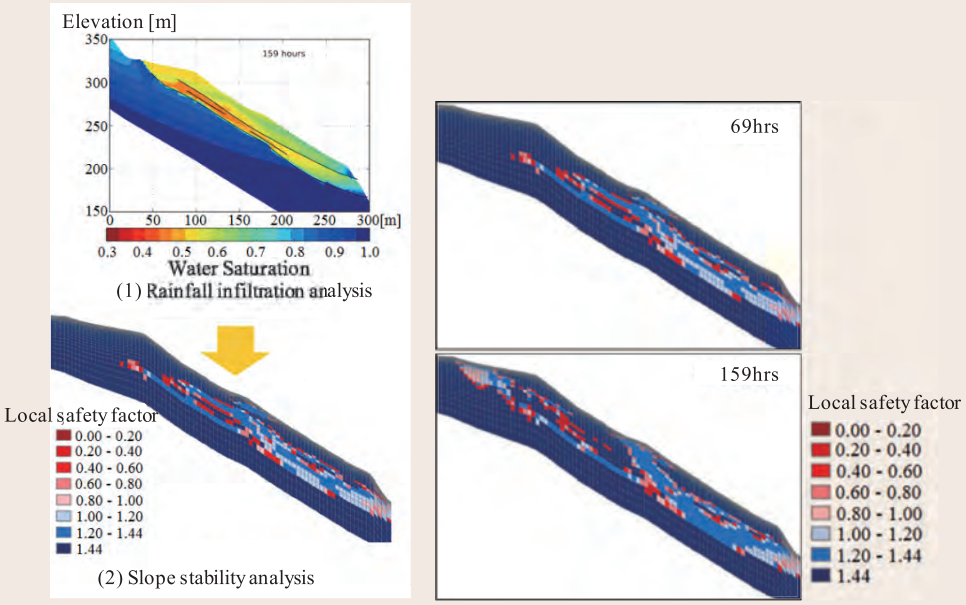


Fig. 1: Conceptual diagrams of a newly constructed rainfall and slope stability estimation method (left) and results of the application to a slope field (right). (a) Conceptual diagrams of a rainfall and slope stability estimation method, (b) Results of application to a slope field

First, a rainfall infiltration analysis given a change in rainfalls as input data calculates saturation and capillary pressure distribution in the ground (left figure (1)). Second, a slope stability analysis calculates distributions of stress, strain and local safety factor of the ground using the saturation and the capillary pressure data and evaluates a risk of slope failure by a total safety factor computed the stress balance in the ground (left figure (2)). The figures on the right show the results of the estimation method applied to a slope of collapsed sediment in the Shimanto zone which is a characteristic geologic structure in southwest Japan. A slope stability analysis conducted using saturation distribution in the ground acquired by rainfall infiltration analysis given the typhoon 15s' rainfall in 2011. Results show that the safety factor of the ground would decrease locally as time passed from the beginning of the rainfall infiltration.

Fig. 2: Outline of instruments for measuring the dynamic state of sediment in a river

To determine the changes in time and location of the dynamic state of sediment in a river during flooding and transport of sediment, a water quality meter, turbidity meter, and automatic water sampling device were installed downstream. A system was constructed to determine turbidity and sediment composition downstream in real time, in order to provide feedback on sediment transportation and a comprehensive model for the downstream area.

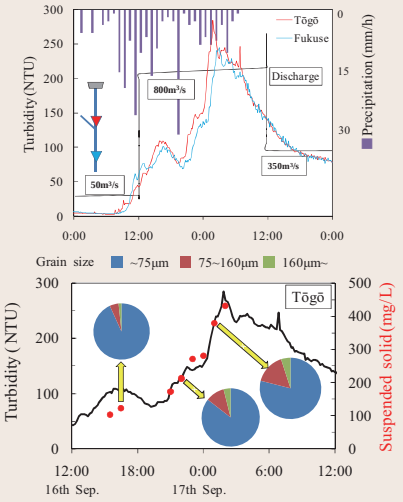


Fig. 3: Results of a sediment dynamic state measurements in the river during the system trial operation and during the passage of a typhoon

Confirmation of real-time data transmission by the measuring instruments as well as monitoring of the change in water quality during the passage of a typhoon in September 2012 was carried out on the Mimikawa River, a second class river system in Miyazaki prefecture, and it was confirmed that the system was functioning sufficiently. The sampled turbid water was analyzed in our laboratory for sediment grain size distribution and mineral composition, as well as water quality properties. Among several factors, the cohesive properties were investigated regarding fine sediment particulates which change in the process of flowing downstream and the origins of the particulates.

Priority Subjects with Limited Terms — **Further Improvement of Facility Operations and Maintenance Technologies**

Demonstration of a Simplified Treatment Technique for PCB Contaminated Transformers

Background and Objective

In 2002, traces of polychlorinated biphenyls (PCBs) were confirmed to exist in electric equipment such as transformers. The establishment of rapid and cost-effective measurement techniques to check for PCB contamination and efficient and economical techniques for cleaning contaminated equipment has been required due to the numerous number of electric equipment that are suspected to be PCB contaminated.

The objective of this study is to improve the PCB measurement technique and develop techniques for cleaning transformers by (1) forcibly circulating a heated insulating oil and (2) spontaneously circulating a heated insulating oil by energizing them in order to remove PCBs, and ultimately reduce the cost of cleaning transformers contaminated with traces of PCBs.

Main results

1 Development of an improved PCB biosensor

The PCB biosensor using an antigen-antibody reaction that was previously developed by our laboratory was improved. We developed techniques to extract PCBs from insulating oil and measure the concentration of PCBs in the oil by constructing flow channels on a substrate with a microstructure (Fig. 1). Using this technique, the measurement time for the PCB biosensor is expected to be reduced to approximately one-third (approximately 40 min) and the amount of required reagents to approximately one-tenth. Regarding the insulating oil collected from the transformers, the PCB concentration measured by our method is in good agreement with that measured by the official method,* demonstrating the high precision of our method (Fig. 2) (V12005).

2 Onsite demonstration tests to clean PCB-contaminated large transformers

Cleaning techniques involving heating and forced circulation and spontaneous circulation by energizing are being developed at our laboratory for investigating PCB-contaminated transformers. Using these techniques, ten regional electric power companies, J-POWER, and the Japan Atomic Power Company jointly carried out onsite demonstration tests at sites where transformers are either stored or used. In the cleaning test involving heating and forced circulation at a site where transformers were stored, the temperature of the cleaning oil was decreased from the conventional 70°C to 40°C to reduce the cost required for cleaning, and three large transformers were cleaned (Fig. 3). In the cleaning test involving spontaneous circulation by energizing, four large transformers connected to the source of a power system were cleaned daily for at least 90 days at their site of use. The results of each demonstration test satisfied the PCB criteria set by the Ministry of the Environment. The results were reported to the PCB Treatment Technology Council of the Ministry of the Environment.

3 Confirmation of PCB removal efficiency by analysis of PCB balance

To verify the PCB removal efficiency, we analyzed the PCB balance before and after cleaning in the onsite demonstration tests involving heating and forced circulation and spontaneous circulation by energizing in order to estimate the PCB removal efficiency. For the former method, 99.2 to 99.7% of the PCBs contained in the oil and structural members of the large transformers were removed by cleaning at 40°C, giving a PCB removal efficiency comparable to that obtained at 70°C. Similarly, for the latter method, 99.3 to 99.7% of the PCBs contained in the large transformers were removed by cleaning. As explained, a PCB removal efficiency of at least 99%, which was our initial target, was achieved and most of the PCBs contained in the transformers were thus demonstrated to be removed by the two cleaning techniques (Table 1).

* The official method refers to the test method described in the standards regarding general waste subject to special control and industrial waste subject to special control (see Table 2, Analysis Method of PCBs in Oil, Ministry of Health, Labour and Welfare, Notification No. 192 of 1992).

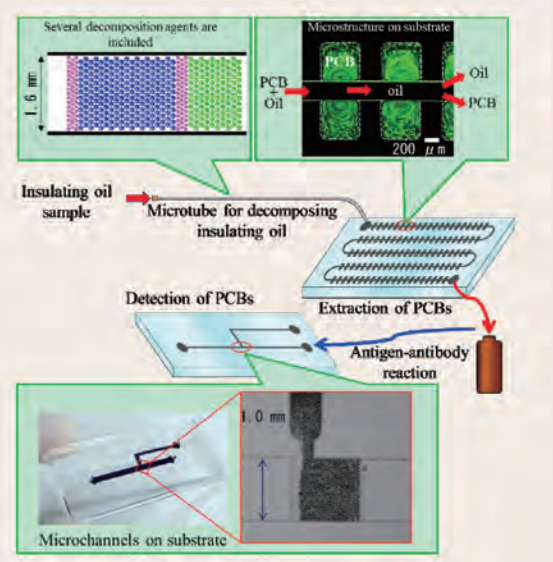


Fig. 1: PCB biosensor developed by microfabrication technology

PCBs are extracted from the insulating oil in the flow channels on the substrate with a microstructure via microtubes filled with an oil decomposition agent. The PCBs in the extracted oil are detected on the substrate with microchannels by an antigen-antibody reaction.

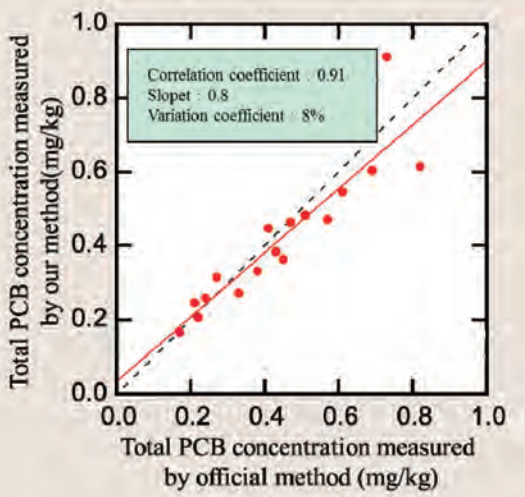


Fig. 2: Correlation between the result obtained using the biosensor developed by microfabrication technology and the result obtained by the official methods

The figure shows the correlation between the total PCB concentrations measured by our method and the official method for 18 samples of insulating oil collected from transformers. In the future, we aim to improve the accuracy so that our method can be approved as an official method.

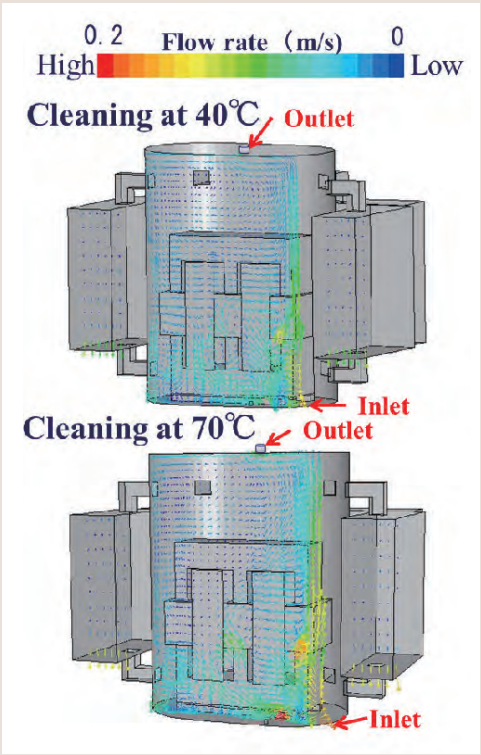


Fig. 3: Simulation of the flow of cleaning oil in a transformer during cleaning involving heating and forced circulation for cleaning oil temperatures of 40 and 70°C

It is assumed that the amount of oil in the transformer is approximately 14,000 L, the flow rate of the cleaning oil at the inlet is approximately 250 L/min, and that the oil is drained from the outlet and recirculated. The flow rate is almost the same regardless of the temperature. It was found that the cleaning oil circulates throughout the transformer even when the temperature is 40°C.

Table 1: Results of evaluating PCB removal efficiency by balance analysis

The amount of PCBs attached to the container of the transformer (per area) and the amount contained in the structural members (per weight) were measured to analyze the PCB concentration before and after cleaning using the surface area of the container and the weight of the structural members. The rates of PCBs removed by cleaning were compared with respect to the total amount of PCBs before cleaning.

Cleaning technique	Test location	Cleaning conditions	Removal rate(%)
Heating	A	Forced circulation at 70℃	99.1
	B		98.9
	C	Forced circulation at 40℃	99.2
	D		99.6
	E		99.7
Energizing	F	Spontaneous circulation for at least 90 days	99.7
	G		99.7
	H		99.5
	I		99.3

Priority Subjects with Limited Terms — **Further Improvement of Facility Operations and Maintenance Technologies**

Development of a Maintenance Scheme for Aged Power Transmission and Distribution Facilities

Background and Objective

It is predicted that a large amount of power equipment introduced in the high economic growth period will require replacement within a few decades. As such, the development of power equipment maintenance technologies for the standardization of maintenance and replacement of aged power equipment, as well as cost-effectiveness, are important.

This project provides equipment replacement planning support tools with equipment operation information and device reliability as evaluation criteria, for the sophistication of equipment diagnosis technology essential for rational maintenance control as well as to support equipment replacement planning.

Main results

1 Establishment of a strategic life estimation method of a power transformer based on the stress-strength life estimation method considering regional characteristics

Insulation paper degradation in a transformer may change due to the load history of the transformer. Moreover the stress applied to the insulation paper (mechanical force) may change due to the lightning-strike frequency and network structures. Based on the stress distributions and degradation of insulation papers in a transformer, we developed a probabilistic method to estimate the degradation of a transformer as shown in Fig. 1. A comparison is made of estimated life distribution considering conventional life estimation and stress distribution based on mechanical force reduction due to insulation paper degradation and the necessary strength found by the electromagnetic force dependent on maximum short-circuited current. As a result of this comparison, it was discovered that the estimated life of the transformer may increase as shown in Fig. 2 (H12013).

2 Clarification of cost reduction benefits of introducing the strategic life estimation method into maintenance planning of power transformers

It was discovered that life estimation of a transformer can be performed based on the power equipment management support tools using the failure history of the transformer and the lighting-strike density of the area where the transformer is located. It is assumed that Japan has been using about fifteen thousand 66kV transformers in substations of towns and cities. Based on the assumptions of 10,000 transformer and this total number remains the same, the total required cost based on the equipment replacement and diagnosis cost has been estimated with developed tools. The total maintenance cost appears to decrease by approximately 40% based on the stochastic estimation of transformer maintenance costs (H12013).

3 Collection of various diagnostic data with electric power utility companies Investigation of aging mechanism of power cables and transformers

Various diagnosis data for the actual power apparatus are essential for effective application of the supporting tools. As for the transformers and power cables, the cooperative work with power utility companies that actually operate the power apparatus is very effective to collect the diagnostic data. Presently, we have been accumulating the diagnostic data for the transformers and the power cables by on-site diagnosis and the investigation of the deterioration as shown in Fig. 3. We are building up the database for the deterioration diagnosis based on the collaborative researches and we have developed the diagnostic techniques applicable to the on-site diagnosis and to the strategic maintenance.

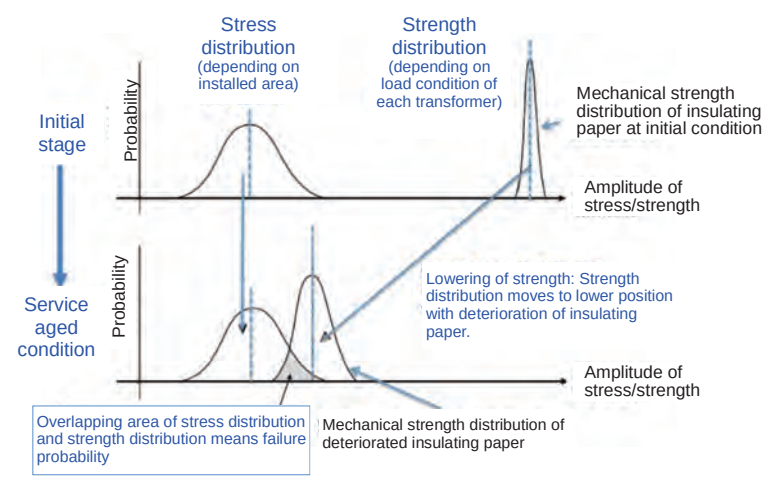
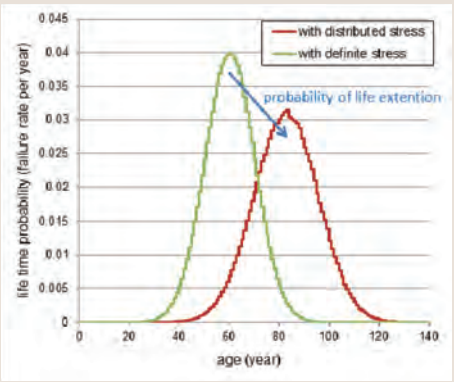
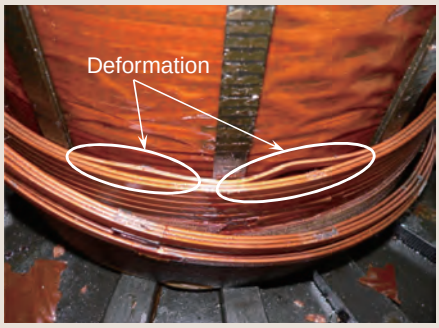


Fig. 1: The concept of stress-strength life estimation method of power transformers based on regional characteristics

The life of a transformer may depend on the overlapping of stress and strength. Normally the strength of a coil will reduce as it ages, increasing the likelihood of breakdowns. The strength of distribution transfers from the right hand side to the left hand side. On the other hand, the overlapping of stress and strength may depend on the location where the transformer is used. Therefore, maintenance personnel must evaluate life with consideration to the degree of overlapping for each transformer.

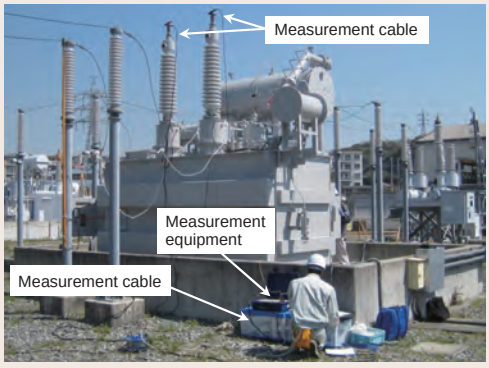




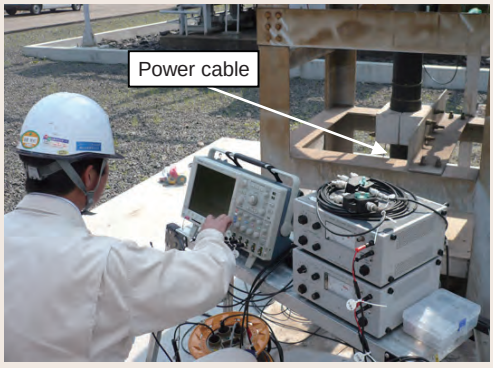
Deformed transformer winding based on the given short-circuited current (mechanical stress)

Fig. 2: Life estimation of power transformers based on the short-circuit electro-motive force (This example indicates the average life of 60 years and the standard deviation of 10 years until the average polymerization decreased to 450.)

If stress distribution is not considered, the life of a transformer will be determined by the maximum short-circuited current. However, if we assume that the maximum current of a transformer depends on the location where it is used, then the life of the transformer may increase as shown in this figure.



(a) Diagnosis of power transformer winding abnormality irradiation materials



(b) Partial discharge measurement of power cables

Fig. 3: On-site measurements at the power equipment

On-site measurements of power equipment such as transformers and cables have been performed to acquire real data.

Priority Subjects — **Further Improvement of Facility Operations and Maintenance Technologies**

Development of Soundness Assessment Techniques for Aged Overhead Transmission Steel Towers

Background and Objective

The aging of overhead transmission steel towers constructed in the high economic growth period has progressed rapidly, giving rise to a need for the standardization of their repairing and rebuilding, which must also be performed with efficiency. Meanwhile, The 2011 off the Pacific coast of Tohoku Earthquake, larger accelerations than these observed in The Southern Hyogo prefecture earthquake in 1995 were observed, and as such, it is also necessary to gain an understanding of seismic performance of steel towers against high-level earthquake ground motion.

In order to contribute to the efficiency and rationalization of maintenance for aging overhead transmission steel towers, this project aims to develop comprehensive diagnostic methods for their soundness, including a remaining life assessment considering corrosion and fatigue, a more efficient corrosion inspection method and a foundation stability assessment. In addition, we clarify the seismic margin of steel towers considering the elastic-plastic behavior against high level earthquake ground motion.

Main results

1 Evaluation of the corrosion rate inside steel pipes of transmission towers

For clarification of the mechanism of corrosion inside steel pipes of transmission towers and for quantitative evaluation of the corrosion rate, corrosion environment measurement devices were introduced and an exposure test of steel pipes with atmospheric corrosion monitoring (ACM) sensors*1 was begun at CRIEPI's Yokosuka coastal testing field (Fig. 1). In the exposure test, output of ACM sensors, temperature and relative humidity inside/outside and along the inside of the steel pipes were measured. The results revealed that, in a coastal environment, corrosion rate inside steel pipes depends on the season, the corrosion rate is greater at low temperature and dry seasons than at high temperature and humid seasons. Results also revealed that the corrosion rate inside steel pipes depends on the position, for example more sever corrosion was observed at the end than at the center (Fig. 2) (Q12003).

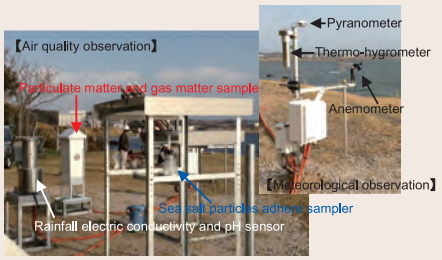
2 Assessment of the applicability of corrosion inspection method for steel pipes

To establish an inspection technique of the corrosion inside steel pipes at low cost and high efficiency as an alternative to impact hammer or bore scope inspections, we proposed a nondestructive inspection using a high frequency guided waves method*2 and a dry type phased array ultrasonic thickness measurement*3 with conformable wedges*4, and verified the performance. The high frequency guided waves method is expected to quickly screen the presence of corrosion as a brief inspection. On the other hand, as a detailed inspection, the phased array ultrasonic measurement provides a profile of corrosion without fluid couplant. Based on a basic study of measurement conditions such as the relationship between signal response and steel pipe shape, we applied the proposed method to corrosion inside an actual aged steel pipe. As a result, we confirmed that the proposed method could identify the corrosion with practical accuracy (Fig. 3) (Q12004).

3 Evaluation on steel transmission tower responses during galloping vibration based on recorded data in a field observation system

The field observation system on an ultra-high voltage transmission steel tower maintained by TEPCO in Fukushima recorded responses of the tower during galloping vibration*5 caused by low atmospheric pressure passing. Based on the obtained data, it was identified that a large amplitude of cable vibration due to galloping vibration had been observed for more than a four hour period. In addition, it was clarified that the maximum cable tension was more than twice that of buffeting responses under the same wind level as galloping. Moreover, an axial force amplitude of a bracing member was about three times as large as that of the buffeting responses (Fig. 4). These observed data help to develop fatigue lifetime prediction method of steel transmission tower.

*1 Sensor for measuring the corrosion rate of metal. In this sensor corrosion current, that is a kind of electrochemical signal, flows between anode and cathode due to environmental corrosion factors.
*2 An approach to inspect thickness loss of pipes in power stations using guided waves whose wave lengths are shorter than the wall thickness of the inspected pipe.
*3 Thickness measurements by dry coupling as accurate as the typical ultrasonic thickness testing.
*4 Wedges put in ultrasonic transducers and conformable to the geometry of test object, which are filled with non-flowable gel instead of resin to make the ultrasonic testing simple and quick.
*5 Up and down large amplitude vibration of a conductor due to strong winds and snow or ice accretion on the conductor

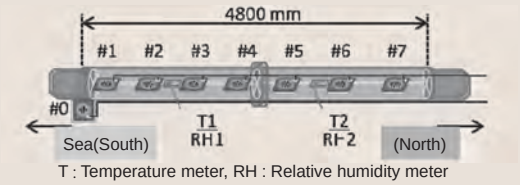


(a) Corrosion environment measurement devices (from March 2013)

(b) Exposure test of horizontal steel pipe members (from August 2012)

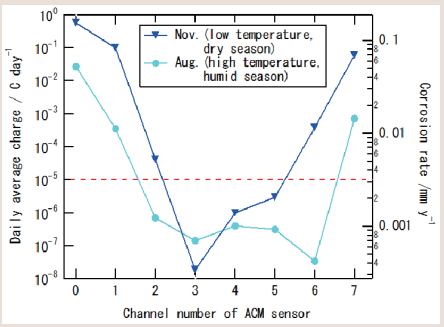
Fig. 1: Corrosion environment observation and exposure testing situation

In regards to corrosion environment observation, measurement of meteorological factors (such as wind direction and speed, solar radiation, temperature, relative humidity, and time of wetness) and measurement of air quality (such as sea salt, sulfur dioxide, rainfall amount, and electric conductivity and pH of rainfall) will be conducted. For the exposure test, the corrosion rate and wet condition inside steel pipes are evaluated. The corrosion rate is estimated using atmospheric corrosion monitoring (ACM) sensors. Steel pipes were arranged horizontally or with slope to ground which simulates horizontal and bracing members, respectively.



T : Temperature meter, RH : Relative humidity meter

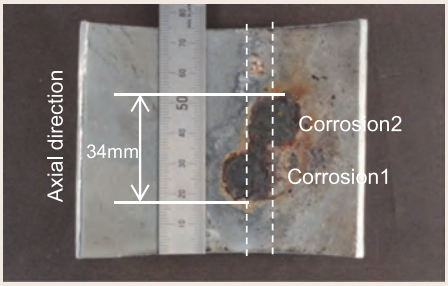
(a) Schematic diagram of the arrangement of ACM sensors inside/outside steel pipe at the exposure test



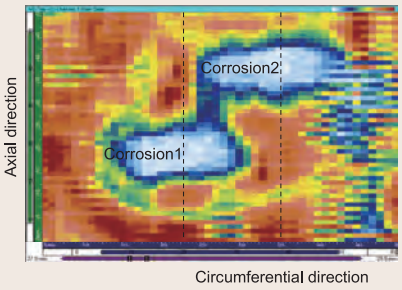
(b) Seasonal corrosion rate inside/outside steel pipe

Fig. 2: Results of corrosion test inside/outside steel pipe

The results of an exposure test on horizontally arranged steel pipe revealed that the corrosion rate is largest on the outside, followed by on the inside at the ends, then the inside at the center. The corrosion rate in the low temperature season was high, which is considered to be due to the fact that water film from dew tends to form easily in this season, and this film contributes to corrosion. The minimum value of the ACM sensor for estimation of the corrosion rate is 10^{-5} C day^{-1}, which corresponds to a corrosion rate of 0.003 mm year^{-1}.



(a) Test specimen with corrosion inside an actual aged steel pipe



(b) Measurement result using proposed method

Fig. 3: Nondestructive inspection method for internal corrosion of steel pipes

Nondestructive testing is proposed in which ultrasonic transducers scan a pipe member in its axial direction using high frequency guided waves propagating along circumferential direction to detect the presence of corrosion, and the phased array ultrasonic testing technology using dry coupled conformable wedges is subsequently used to profile the corrosion.

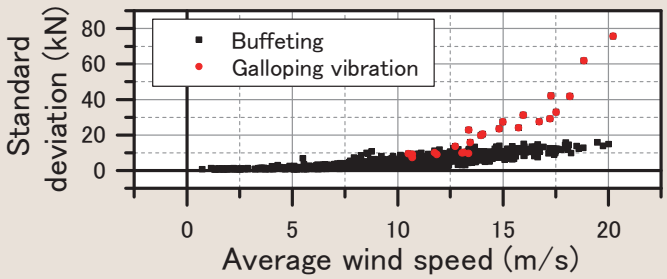


Fig. 4: Observed response data of the tower during galloping vibration

Response data, such as cable tensions, axial forces of tower members and so on, and movie data which recorded cable motion were obtained during galloping vibration. In Fig. 4, a relationship between average wind speeds and axial forces of a bracing member at the panel below a cross-arm effected by cable tension variation was shown. An axial force variation of the bracing member during galloping vibration was three times as large as that of buffeting responses under the same average wind speed.

Priority Subjects — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Improvement of Operation and Control Technologies to Diversify Fuel Types for Pulverized Coal-Fired Power Plants

Background and Objective

The utilization of low grade coals is sought to diversify fuel types in pulverized coal-fired power plants. For the cost reduction of maintenance and inspection and for environmental preservation, countermeasures to the sulfidation corrosion of boiler tubes and trace elements control are necessary in coal-fired power plants. In this research subject, the guideline for the operating conditions of a mill and a burner, and a blending method, etc. are under development to use low HGI coal*1 (which has low grindability) and low volatile coal (which is low combustibility) in existing pulverized coal-fired power plants. In regards to countermeasures for sulfidation corrosion, an evaluation method of sulfidation conditions and coating technology for the tube will be developed. Estimation methods of trace elements behavior such as Hg, B, Se, and emission control technologies are also under development.

Main results

1 Grindability and combustibility of low HGI coal

The grindability of the low HGI coal (WC coal) produced in Australia was evaluated using a roller mill (coal grinding rate; 300 kg/h), which had a similar structure to that in actual power plants (Fig. 1(1)). When the low HGI coal was grinded to a similar particle size to that of conventional bituminous coal, the grinding power for the low HGI coal became about twice of that for the bituminous coal (CL coal) (Fig. 1(2)). The weight loss of metal test pieces installed on a roller surface was measured to investigate the erosion characteristics concerned with maintenance cost for a roller mill. The weight loss of the metal pieces during the grinding of the low HGI coal was also approximately twice of that during the grinding of the bituminous coal. Both the grinding power and the weight loss of the pieces were reduced when the pulverized particle size was set coarser.

The combustibility of the low HGI coal was evaluated using a coal combustion test facility (coal combustion rate; 100 kg/h). Even though the particles of the low HGI coal were coarser, sufficient combustion efficiency could be kept because the volatile content of the low HGI coal was high. NOx emissions at the exit of the furnace could also be kept low because of the low nitrogen content in the low HGI coal (Fig. 1(3)).

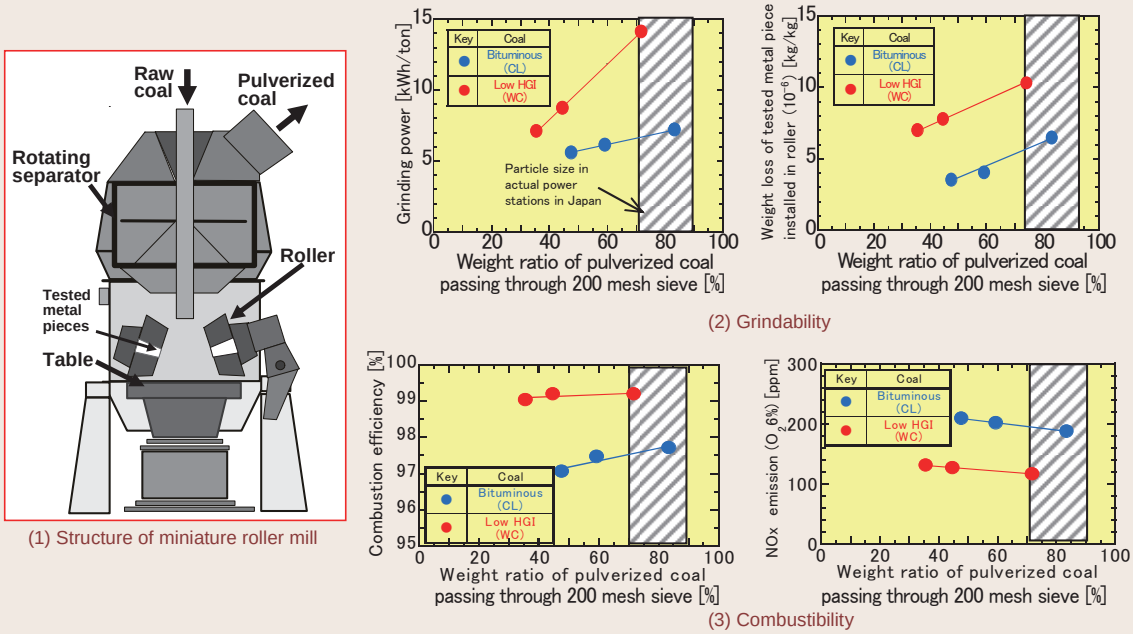
To use low HGI coal, one option is to blend it with a high grindability coal, and another is to set the particle size coarser in a mill (M12008).

2 Development of a coating technology for preventing sulfide corrosion on boiler tubes - Effects of surface preparation -

In order to investigate the effects of surface preparation on sulfidation corrosion-resistance, the corrosion tests were performed on metal substrates prepared as per three preparation grades (U.S.A steel structure painting councils; SSPC-SP-10, SSPC-SP-6, SSPC-SP-3*2) in our laboratory and at an actual power plant. For the substrate prepared as per SSPC-SP-6, the thickness of corrosion layer on a coated part was reduced to 10 percent or less compared with an uncoated part. The metal substrate prepared as per SSPC-SP-6 was found to have better corrosion-resistance than that prepared as per SSPC-SP-10 (Fig. 2). The sulfidation corrosion-resistance on metal substrate prepared as per SSPC-SP-3 was also high, though there was the problem of existing corrosion layer detachment. (M12006)

*1 HGI (Hardgrove grindability Index) is an evaluating factor for coal hardness. As HGI decreases, coal becomes harder to grind. The HGI of bituminous coal utilized in Japan ranges from 40 to 70. The HGI of low HGI coal in this study is lower than 40.

*2 SSPC-SP-10: A near-white blast cleaned surface. Other foreign matter is completely removed except for very light shadows. SSPC-SP-6: Commercial blast cleaning. It requires removal of loose scale, rust, and other contaminants. SSPC-SP-3: Power tool cleaning. It will remove only loose scale, rust or other detrimental foreign matter.



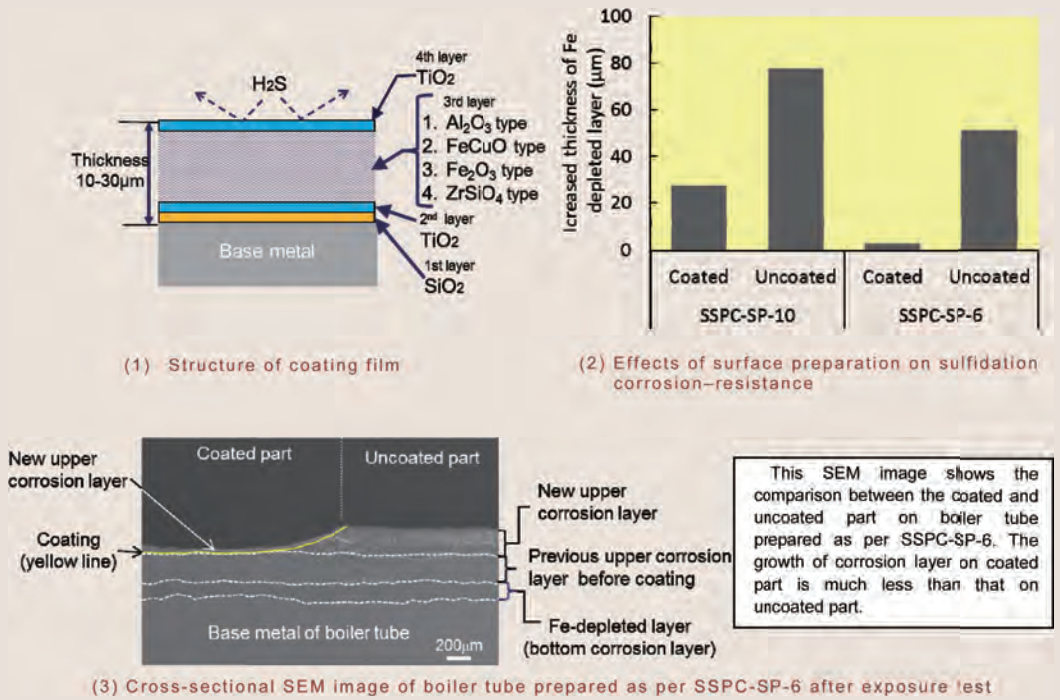
(1) Structure of miniature roller mill

(2) Grindability

(3) Combustibility

Fig. 1: Influence of pulverized coal size on grindability and combustibility

The grinding power of low HGI coal is around twice of that for the bituminous coal when the passing weight ratio of a 200 mesh (75μm) sieve is 70%. The weight loss of metal test pieces during the grinding of low HGI coal was close to twice of that of bituminous coal (CL coal). Both the grinding power and the weight loss of the pieces decreased as the passing weight ratio of 200 mesh sieve increased. The combustibility of the low HGI coal is better than that of the bituminous coal. It may be acceptable to set the particle size coarser in a mill to use low HGI coals, since the sufficient combustion efficiency is maintained and NOx emissions do not worsen.



(1) Structure of coating film

(2) Effects of surface preparation on sulfidation corrosion-resistance

(3) Cross-sectional SEM image of boiler tube prepared as per SSPC-SP-6 after exposure test

Fig. 2: Effects of surface preparation on sulfidation corrosion-resistance of the coating film

The structure of coating film is designed in terms of the chemical reactivity with H_2S and the coal ash elements (Na, K, etc.), and wear resistance. In order to verify the corrosion resistance of the film, an exposure test utilizing Al_2O_3 type film was performed for 3700 hours in an actual power plant. The result showed that the metal substrate prepared as per SSPC-SP-6 had higher corrosion-resistance than that prepared as per SSPC-SP-10.

Priority Subjects — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Development of Upgrading Technology for Low-Grade Energy Resources

Background and Objective

The co-firing of biomass with coal is promoted as one of the CO_2 emissions reduction measures in coal-fired power plants. However, the mixing rate of biomass is limited to several percent, due to the increase in grinding power consumption as a result of the difficulty of biomass grinding with ordinary coal mill.
The use of brown coal is also attracting interest as a means of diversifying fuels for coal fired power plants, although it requires dewatering and control of spontaneous ignition.
This project aims to develop carbonization technology to improve the quality and grindability of biomass, and a dewatering technology that upgrades the quality of brown coal using the water-absorbing property of dimethyl ether (DME).

Main results

1 Development of carbonization technology for woody biomass

To increase the mixing rate of biomass in existing coal-fired power plants, we started development of a carbonization technology for woody biomass. The co-firing of carbonized biomass (char) at a 10cal% mixing rate in an actual coal-fired power plant will require several hundred tons of char per day. We set up an experimental facility for studying carbonization processes and selected the indirect heating rotary kiln*1 as the carbonizer of the facility in terms of scale-up (Fig. 1). A test run of the facility using wood chip was carried out at a feed rate of 140kg/h and a carbonized temperature range between 300 and 600 degC, and the performance of the facility was confirmed (Fig. 2).

2 Grindability evaluation of carbonized woody biomass

The carbonized woody biomass shows various fuel properties depending on the carbonization temperature and the residence time. The mixed grinding test of the coal and carbonized woody biomass (char) was carried out by using a test roller mill. The grinding power for the mixture of coal and char at the carbonization rate*2 of 58% became 10% higher than the typical value for coal (Fig. 3). However, volatile matter in the woody biomass was decreased, and the energy recovery rate of the woody biomass was decreased at higher carbonization ratio, it is important to optimize the carbonization rate in view of the energy balance.

3 Development of DME dewatering technology for brown coal

The technologies of dewatering and spontaneous ignition control are major issues in the expansion of brown coal usage and as such, we are developing an effective dewatering technology using DME. We clarified the relationship between the DME flow rate and the dewatering ratio (weight percent of removed moisture to the original moisture of brown coal) through a laboratory scale experiment. There was little difference in the dewatering ratio as a result of change to the DME flow rate. This means the required time of the dewatering processing can be reduced.

*1 There are direct heating and indirect heating processes for carbonization. The indirect heating carbonizer can easily control carbonization temperature, and yields the volatile gas and char separately. A carbonizer with the horizontal cylindrical vessel which rotates slowly and heats the raw material uniformly is called the rotary-kiln.
*2 The carbonization rate means the carbon content in fuel on dry ash free basis. In general, the carbon content is increased at higher carbonization temperatures.

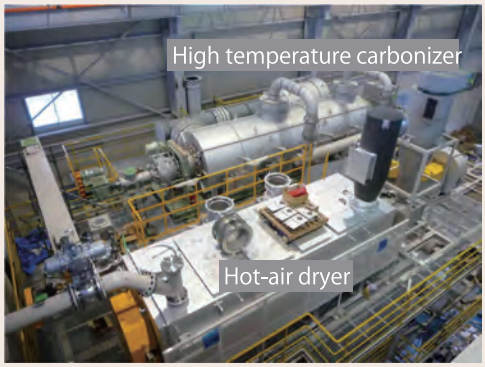


Fig. 1: Carbonization experimental facility

The hot air dryer has a biaxial stir, and the throughput is 300kg/h for the sewage sludge cake (moisture 80%). The inner cylinder of the carbonizer is made of nickel alloy, which has excellent heatproof and anti-corrosion properties, and enables carbonization at 650 degC.

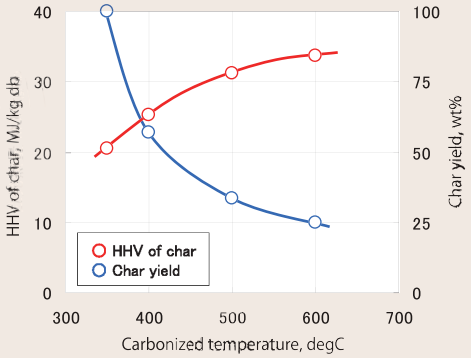


Fig. 2: Relationship between HHV of char, char yield and carbonization temperature

Carbonization of wood chip (moisture 50%, feed rate 140kg/h) showed that HHV of char improved with the rise of the carbonization temperature, and the char yield decreased. At 500℃, HHV of the char reached approximately 1.5 times that of the raw material, and the char yield lowered to approximately 1/3 of the raw material.

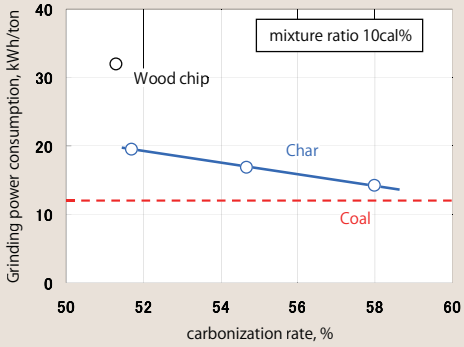
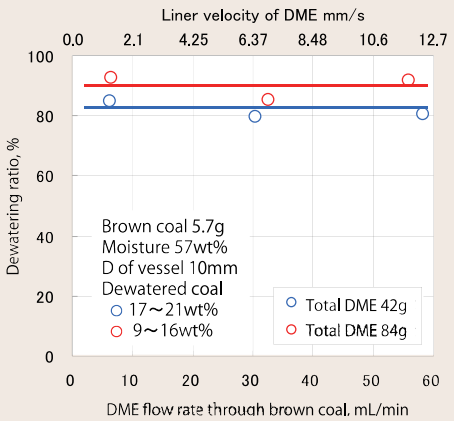


Fig. 3: Example of mixed grinding test result of coal and char

Char is mixed with coal by 10 cal%, and the grinding test was carried out in a test roller mill. The grinding power of wood chip mixture with coal became more than twice that of coal, and the grinding power of char decreased as the carbonization rate was raised.



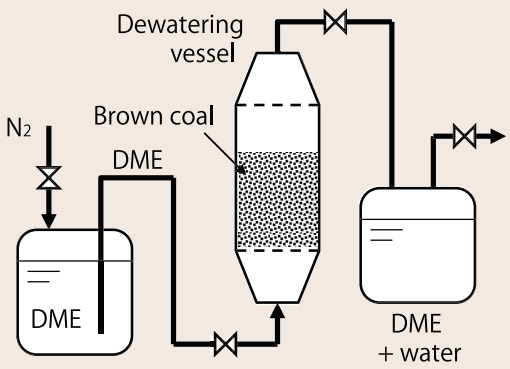


Fig. 4: Relationship between DME flow rate and dewatering ratio

There was little change in the dewatering ratio when the DME flow rate was increased and the contact time of the brown coal with DME was shortened. It was possible to dewater the brown coal when DME penetrated the brown coal layer at 10mm/s.

Priority Subjects — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Development of Enhanced IGCC and Low Carbon Technologies

Background and Objective

Integrated coal gasification combined cycle (IGCC) power generation, which is a highly efficient and environmentally friendly system, is an important technology for the electric power industry as an option for coal-based thermal power plants. CRIEPI has been involved in the IGCC project research since the initial stage of development to support the design and operation of the Nakoso IGCC demonstration plant, and has also been developing a hot-gas cleanup system to improve the thermal efficiency of a next-generation IGCC system. Moreover, CRIEPI has proposed a highly efficient IGCC system with CO_2 capture (Oxy-fuel IGCC system) to solve the problems of carbon capture and storage (CCS) technologies that cause a significant drop in power generation efficiency and an increase in cost.

In this research, to promote introduction of a commercial IGCC plant, we support the operation of a demonstration IGCC plant, and build the technique to assess the design and operation of a commercial IGCC plant. We also evaluate the impact of a hot-gas cleanup system on the thermal efficiency and the cost of an IGCC system, and build up the technological basis for an oxy-fuel IGCC system.

Main results

1 Supporting Activities for the IGCC Demonstration Project and Evaluation of Coal Adaptability

The gasification performance of the IGCC demonstration plant was predicted for several test coals, using our one-dimensional numerical simulation technique and a gasification reaction rate analysis under high temperature and elevated pressure. A sensitivity analysis was conducted to predict the influence of operating conditions, such as air ratio, on gasification performance (Fig. 1), and the results were reflected in the demonstration tests. Another analytic method was also built to evaluate the molten slag behavior related to the stable operation of the gasifier, and a technique to evaluate coal adaptability based on the numerical simulation techniques was established (Fig. 2). Moreover, the mechanisms of a blockage in the syngas cooler of the demonstration plant were clarified. These activities have contributed toward the success of the IGCC demonstration project.

2 Evaluation of the Economic Impact of Hot-Gas Cleanup System

The introduction of a hot-gas cleanup system was estimated to reduce investment cost by 35% compared to the conventional wet gas cleaning system due to dry processes reducing the number of reactors, heat exchangers and pumps. On the other hand, the operational cost of the hot-gas cleanup system increased due to the costs of impurity sorbents and detergents. The cost of electricity from IGCC with the hot-gas cleanup system was evaluated to ultimately be lower than that with the wet gas cleaning system, due to the fact that the higher efficiency contributed to reducing fuel costs.

3 Development of Fundamental Technologies for Oxy-Fuel IGCC System*

In an oxygen-CO_2 blown coal gasifier in the oxy-fuel IGCC system, a gasification reaction is expected to promote by supplying CO_2 as a gasifying agent, but the temperature in the gasifier falls due to the higher molar specific heat of CO_2. In order to examine the influence of supplied CO_2, gasification experiments were conducted using the 3t/d coal research gasifier installed in CRIEPI. The CO_2 and oxygen concentrations in gasifying agents, and the coal feeding ratio of reductor to total were changed. As a result, reaction behavior in the gasifier was clarified experimentally (Fig. 3) and useful data to predict the gasification performance were obtained. (M12005)

In a hot-gas desulfurization process in the oxy-fuel IGCC system, carbon deposition reaction possibly deteriorates the performance of desulfurization sorbents. We proposed a recirculation of gas turbine exhaust to the upstream of desulfurization process. Carbon dioxide and steam in the exhaust significantly prevented the carbon deposition in the experiments using simulated gas. (M12001)

* This work was partially supported by New Energy and Industrial Technology Department Organization (NEDO).

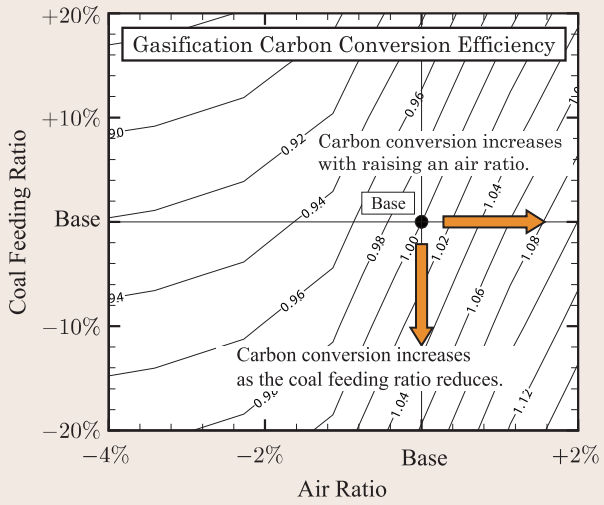


Fig. 1: Example of the prediction of gasification performance

Our one-dimensional numerical simulation technique enabled prediction of gasification performance of the IGCC demonstration plant. This figure is a two-dimensional map of the gasification performance by two operating parameters*1. The gasifier carbon conversion efficiency*2, which is an index of the gasification performance, is shown here.

*1 The air ratio is the ratio of the amount of supplied air to that of stoichiometric air. The coal feeding ratio indicates the ratio of the amount of reductor coal to total coal.
*2 The gasification carbon conversion efficiency is the ratio of the amount of carbon in syngas to that of carbon in coal and char.

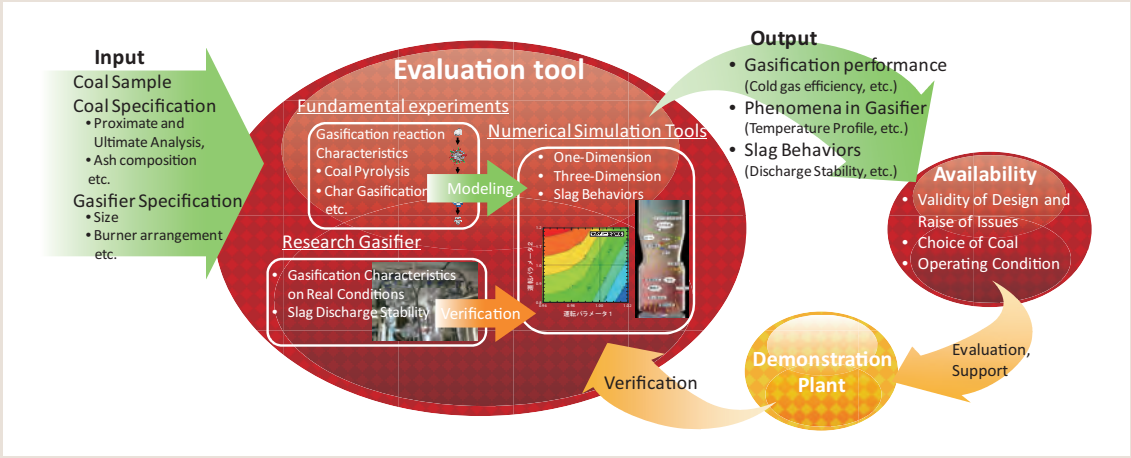
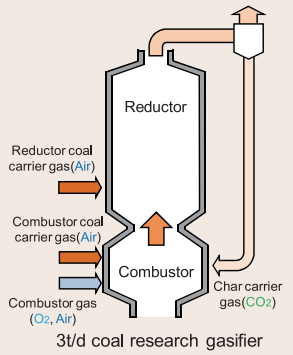


Fig. 2: Outline of the evaluation method of coal adaptability to the IGCC system

The technique to evaluate coal adaptability to a commercial IGCC plant has been established on the basis of fundamental experiments with a sample of candidate coal and numerical simulation tools verified in the demonstration plant tests. The one-dimensional numerical simulation tool is used for the sensitivity analysis of gasification performance, and the three-dimensional numerical simulation tool and the slag-behavior analysis tool are used for extensive prediction of phenomena in the gasifier.



*3 Cold gas efficiency is the ratio of energy content in syngas to the energy content in coal.

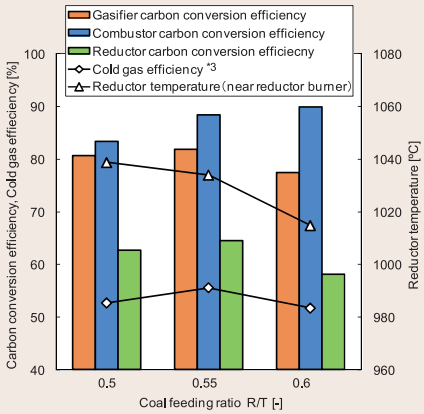


Fig. 3: Influence of coal feeding ratio in the gasification experiments using CO_2 as carrier gas

The gasification experiments, in which CO_2 was used as the char carrier gas, were conducted at various coal feeding ratios (R/T = feeding rate to reductor / total feeding rate), while the air ratio and combustor temperature were set at constant. As the value of R/T reduced, the combustor carbon conversion efficiency fell, whereas the gasification reaction in the reductor was promoted. It was found that the impacts of R/T on the combustor and reductor were different.

Priority Subjects with Limited Terms — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Assessment of System Security with High Penetration of Photovoltaics

Background and Objective

It is important to ensure power system stability (rotor angle stability, frequency stability and voltage stability) following transmission system faults with high penetration of renewable energies primary of photovoltaics (PV).
However, how transmission system faults, which occur when there is high PV penetration, impact on power systems has not yet been fully investigated. Therefore, it is important to clarify the influence and develop countermeasures relating to future power system stability.

The purposes of this project are:
(1) Evaluation of the influence of power system faults on the transmission system
(2) Experimental tests for extracting the characteristics of a Power Conditioning System (PCS) which consists of inverter of the PV with anti-islanding protection
(3) Establishment of numerical PV models for time-domain simulation.
(4) Development of countermeasures against power system stability for the future power system.

Main results

1 Experimental Verification of the Fundamental Influences of Transmission System Faults on Power Systems with High Penetration of PVs

In order to evaluate the fundamental influences of transmission system faults on power systems with high penetration of PVs, rotating synchronous generators G1 (100kVA) and G2 (90kVA), 275kV and 66kV transmission line models, DC power resources which can emulate PV solar panels, and residential-use PCS for PV (Latest PCS*1) were installed in CRIEPI's Power System Simulator. Figure 1 shows a testing system in the simulator. It is assumed that the synchronous generator G2 could be replaced with the PCSs for PV due to the high penetration of PV. The power transfer limit of G1 was used as evaluation criterion for the testing systems which consist of "G1+G2" or "G1+PCSs".
As a result, the power transfer limit of "G1 + PCSs" was around 35% lower than "G1+G2". Figure 2 shows an example of testing results of the rotor angle oscillation of G1. In the case of the "G1+G2" system, the rotor angle of G1 was well-damped after opening three-phase transmission lines (3LO) between BUS2 and BUS3. On the other hand, in the case of the "G1+PCSs" system, the rotor angle of G1 was not damped following the same disturbance (3LO).
Moreover, the experimental tests revealed that the PCSs of PV could be stopped for a short period depending on system configurations such as the length of 275kV or 66kV equivalent transmission line model, the number of the connected PCSs of PV, and the various types of transmission system faults.

2 Dynamic Behavior of Photovoltaic Inverters Responding to High-Voltage Transmission System Faults

Several functions such as (1) the automatic anti-islanding detection relay (IDR), (2) DC control system, (3) protective relay, (4) PV inverter control, and (5) the voltage rise control function were additionally implemented in the numerical model of the PCSs of PV for CPAT*2. The newly installed elements shown in Table 1 are necessary to represent dynamic behavior of the PCSs of PV following system faults.
The performance of the IDR of PV for detecting the condition of the islanding high-voltage transmission system with and without a synchronous generator were examined using CPAT (See Fig. 3) (R12015) (R12016). The IDR always detected the islanding condition for the isolated system without synchronous generators, while the IDR did not always detect the islanding condition for the isolated system with synchronous generators. According to the CPAT simulation results, the IDR could detect the islanding condition less than 170ms after three-phase short-circuit (3LS) faults.
It was also showed that the IDR or high-speed under voltage relay could operate following a single line to ground fault (1LG). It was found that the stoppage time of the PCSs of PV could vary depending on the PV penetration ratio or the mismatch between the total active power generations and loads at PCC before islanding.

*1 Latest PCS model that has a new islanding detection relay named AICOT (Anti-Islanding COntrol Technology).
*2 The CPAT (CRIEPI's Power system Analysis Tools) is developed by CRIEPI. In this study, a transient stability analysis tool of the CPAT is used. The CPAT is used by all 10 electric utilities in Japan.

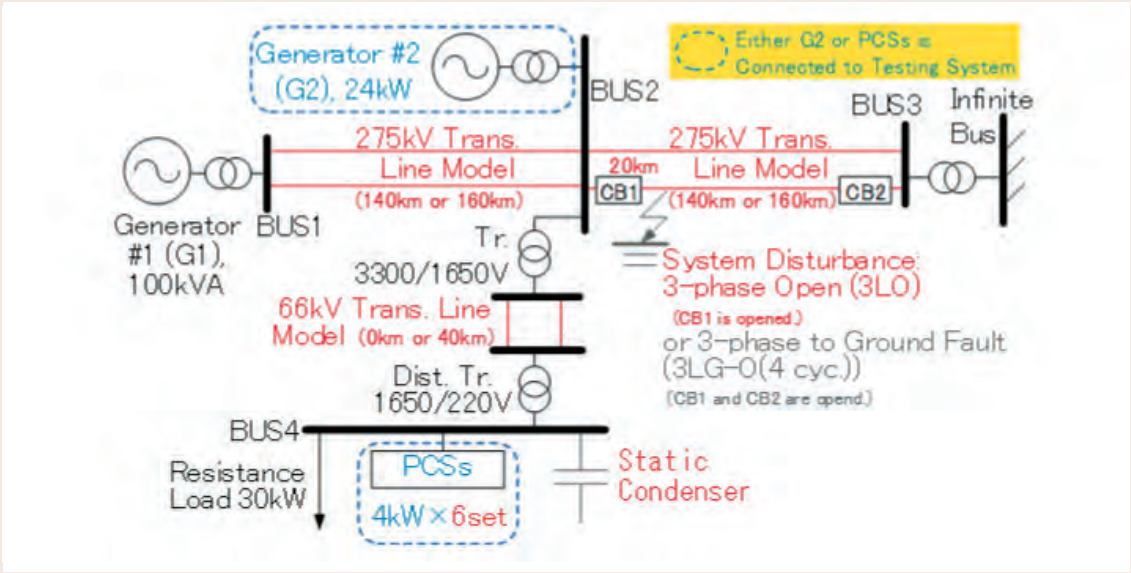


Fig. 1: Testing System in CRIEPI's Power System Simulator

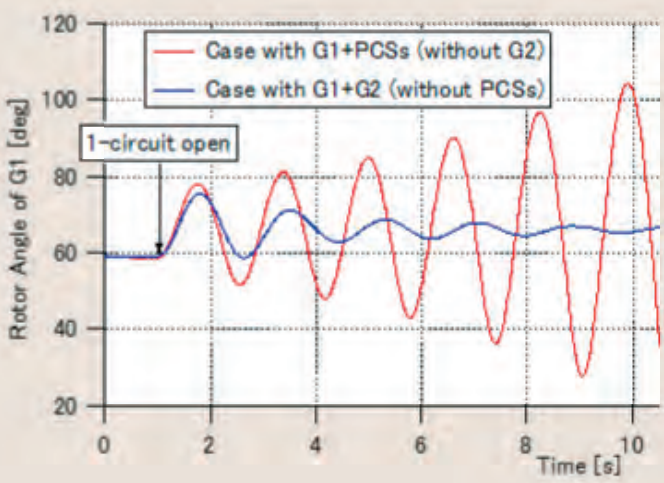


Fig. 2: An example of testing results in CRIEPI's Power System Simulator

Table 1: The Functions of the PCSs Model for PV in the CPAT

Classification	Function
Fault Ride Through	Stoppage Characteristic
	Recover Characteristic
Control Element	(4) Active Power Control
	(4) Reactive Power Control
	(2) DC Control
	(5) Voltage Rise Control
Protective Element (Apparatus & Grid Connected Operation	(3) Overvoltage Relay
	(3) High-speed Overvoltage Relay
	Frequency Relay
Protective Element (Automatic Islanding Detection Relay)	Scheme to detect Jumping Voltage Phase
	Scheme to detect Changing Rate of Frequency
	Variable Reactive Power Scheme
	Frequency Shift Scheme
	(1) AICOT

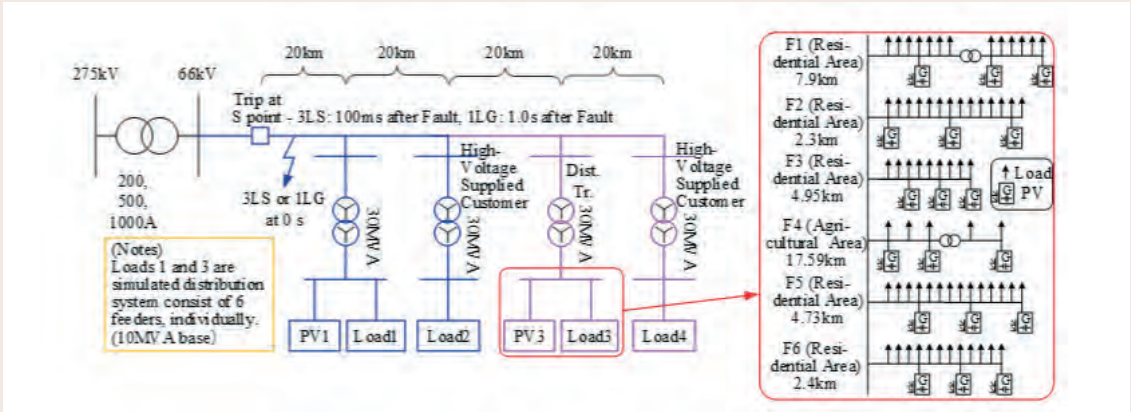


Fig. 3: CPAT Simulation System

Priority Subjects — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Development of a Next-Generation Coordination System for Power Demand and Supply

Background and Objective

Expectations towards renewable energy sources (RES) such as photovoltaic (PV) power generation are intensifying and it is predicted they will penetrate the utility system in high volume. As such, it is necessary to develop techniques to achieve both effective use of RES and preservation of power quality, safety and stability of the utility system at a low cost. The objectives of the research are to establish basic techniques for the distribution system such as restraint of voltage rise, protective cooperation and so on, and to develop coordination system techniques of power demand and supply including a technique for the effective use of distributed power generation.

Main results

1 Development of an islanding prevention method in case of secondary transmission system faults

In addition to an islanding prevention method responding to distribution line faults, it is also necessary to establish a prevention method of islanding*1 that may occur on a wide scale in the case of upper secondary transmission system (66kV) faults upon high PV penetration. In the study, islanding detection characteristics*2 of the marketed PCS for PV use were tested under the condition of parallel operation of rotation type distributed generator (SG) on the assumption of the islanding covering a wide area. The results led to the following findings; islanding duration tends to increase under SG operation. The bigger the rate of PCS capacity is to SG capacity, and the longer the electrical distance between PCS and SG is, the larger the probability of islanding detection within the regulated 3 seconds (Fig. 1). In addition, the conditions under which PCS can detect the islanding were also clarified by a computer simulation using the developed XTAP*3 instantaneous value model (Table 1). (R12020)

2 Evaluation of influence of 3-phase imbalance condition in distribution line on voltage management and development of countermeasures

Voltage management of high voltage distribution lines may be difficult due to the increase of 3-phase imbalance by penetration of large capacity single-phase appliances such as heat pump type water heaters in addition to a PV system. Problems on the voltage management of the distribution line using SVR and effective control method of SVR were analyzed by computer simulation using the 3-phase imbalance analysis program developed by CRIEPI. SVR model was added to the program for the simulation. Results confirmed that SVR might not control distribution line voltage within the proper range and not judge power flow direction exactly by the conventional SVR control method in which SVR monitors only a part of the phases (Fig. 2). As a countermeasure, a method was proposed in which control mode change of SVR through reverse power flow is executed by judgment with the sum of real power flow and the sum of reactive power flow of 3 phases. The validity of the method was confirmed by computer simulation (Fig. 3, Table 3). (R12021).

3 Development of a new reactive power control method to suit the rate of PV output change

When the volume of PV systems installed in a distribution system increases, the required capacity of high-cost control equipment (SVC) may increase in order to suppress voltage fluctuation. Therefore, reactive power control in proportion to the rate of PV output change was proposed as a new method, and the proposed method was evaluated by simulation analyses with residential area distribution system model. The simulation results show that the required capacity of SVC was reduced by the proposed method as much as the constant power factor control at 0.97 (Fig. 4). In addition, the distribution line loss when the proposed method was applied was smaller than that in the case of constant power factor control (Fig. 5). (R12012)

(Notes)
*1 Islanding phenomena in a wide area including plural 6kV distribution lines.
*2 Detection characteristics of "Frequency feedback method with step injection" which is an active type islanding detection method regulated in 2011 which has fast detection and is noninterference.
*3 Instantaneous value analysis program developed by CRIEPI.

Other reports: (R12018)

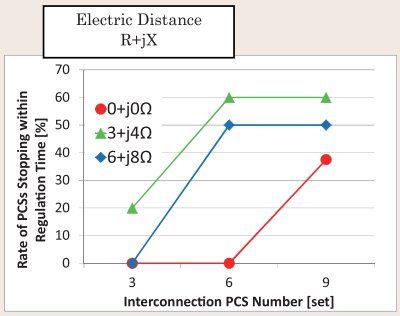


Fig. 1: Relation of PCS/SG capacity, electric distance, detection rate of islanding phenomena

The possibility of detecting islanding phenomena within regulation time increases as PCS capacity/SG capacity becomes greater, and electric distance between SG and PV is larger.
(SG Capacity: 150kW, Method of Reactive Power Variation, PCS Capacity: 4kW/set, new islanding detection method)

Table 1: PCS/SG Capacity, Electric distance, detection rate of islanding phenomena
(SG Capacity : 2MW、PCS : new detective method of islanding)

600kW or more PCS with new islanding detective method is needed to detect islanding within regulation time.

Electric Distance [Ω] / PCS Capacity／SG Capacity	0+j0	1+j1	3+j4	6+j8
0	×	×	×	×
0.3	×	×	○	○
0.4	○	○	○	○
0.6	○	○	○	○

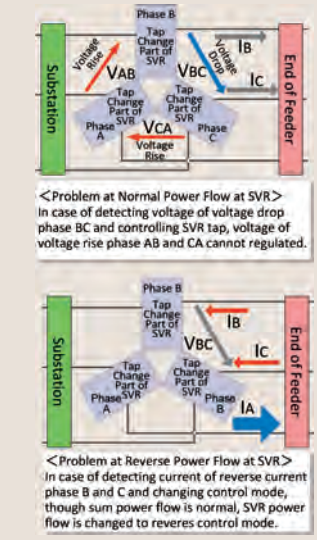


Fig. 2: Problems of present control method

Upper figure shows problems at normal power flow. Lower figure shows problems at reverse power flow.

Table 2: Comparing the present method with the proposed method by PV introduction possibility rate (PIPR)
(PV Introduction Rate = Sum of PV capacity/Feeder capacity)

PIPR is less than 20% with the present method, however increases to 60% with the proposed method.

Control Method		PV Introduction Possibility Rate
Present Method	Detecting Phase AB	20% or less
	Detecting Phase BC	20% or less
	Detecting Phase CA	20% or less
Proposed Method		60%

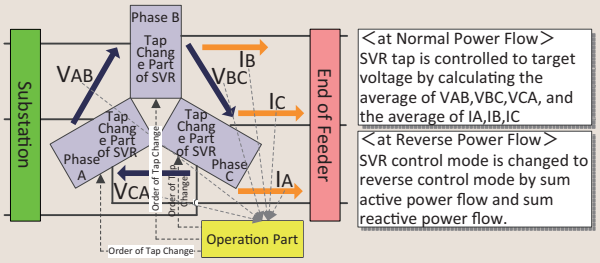


Fig. 3: Proposed SVR control method

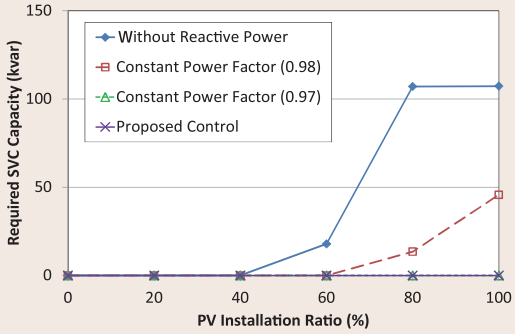


Fig. 4: Comparison of SVC capacity reduction effect between control methods (In case of 4km distribution system of the residential area)

By the proposed method, a similar effect is obtained as that of the constant power factor control (power factor is 0.97).

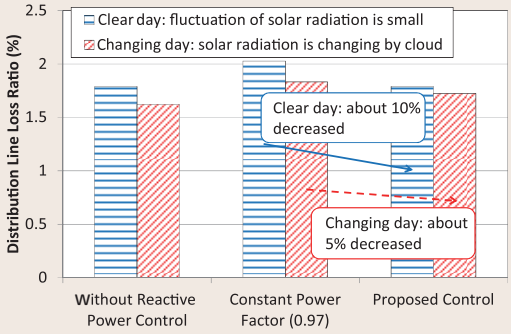


Fig. 5: Comparison of distribution line loss between control methods (PV installation ratio is 100%)

By the proposed method, distribution line loss ratio is smaller than the constant power factor control (10% smaller on a clear day, 5% smaller on a “changing” day).

Next-Generation Communications Network Systems

Background and Objective

Utility communication network systems have been well implemented for the automated operation of power generation and delivery, but have yet to be developed for customer communications such as smart metering, and maintenance and diagnosis of power delivery assets. In addition, communications for power system protection and control are still proprietary and legacy (not IP-based).

This project integrates the fundamental technologies developed in the previous project into practical ones and develops design methods and tools for distribution and customer-side communications networks, sensor networks for power delivery asset condition monitoring, and IP-based wide-area monitoring, protection and control networks.

Main results

1 Communication characteristics evaluation of multi-hop wireless system using 920 MHz band for smart meters

The wireless system using 920 MHz band which draws attention as a candidate for a multi-hop wireless system* for smart meters, needs an efficient communication method to collect data from a large number of meters due to its low transmission rate, though has an advantage in its radio propagation characteristics. We developed a simulation program to evaluate commun ication characteristics in the case of using an open international standardized communication protocol. We showed that the limit of the number of waits for transmission dominantly influences the communication performance due to the random access scheme upon connecting to nearby equipment, and also that the limit of the number of retries for transmission is due to the radio interference from distant equipment upon connecting to faraway equipment (Fig. 1). In order to improve the communication performance, it is important to adjust certain parameters, such as transmission timing, waiting time for transmission, and the number of retries, suited to the environments where the communication equipment is implemented.

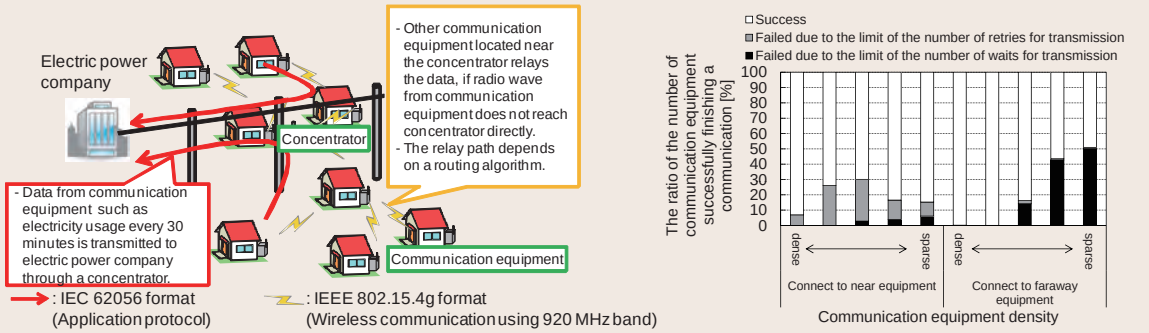
2 Development of a new sensing system using remote optical power supply connectable to wireless sensors

We proposed new multi-point optical sensing system using a remote optical power supply for power transmission line monitoring to achieve efficient use of facilities. In our previous work, the prototype system with wired sensors was developed and demonstrated. This time, we have developed an extended system connectable to wireless sensors which enables us to expand the monitoring area (Fig. 2). In the case of driving the radio receiver with large power consumption, supplied power is charged in the capacitor and the receiver is driven in a short time using its energy. An efficient data collection method was created for simplex sensors that the monitoring station surveys data sending timing of the sensors and controls the timing to start charging of capacitors. We successfully developed and examined a demonstration system applying the above technologies and practical wireless sensors to show that on-site monitoring facilities with no power equipment is feasible.

3 Examination of the applicability of a precise time synchronization scheme to wide-area IP networks

In order to measure and process power system state data precisely for protection and control, their measurement timings must be synchronized throughout the power system. To achieve simple timing synchronization, a time synchronization scheme standardized as IEEE 1588** was evaluated with respect to its expansive applicability to wide-area IP-related networks. While the time synchronization was degraded or not achieved for some cases in conventional networks (Table 1), a time synchronization error of around 1μs sufficient for protection and control was experimentally achieved in Ethernet-based networks dedicated to time synchronization (Fig. 3).

* A wireless system transmitting meter reading data from each smart meter like a bucket brigade, connecting neighboring smart meters.
** A time synchronization error less than 1 μs is achieved for a local area network.



(a) Schematic view of multi-hop communication

(b) Evaluated result of the communication success rate

Fig. 1: Communication characteristics evaluation of the multi-hop wireless system using 920 MHz band for smart meters

(a) The elapsed time from the autonomous transmission of meter readings every 30 minutes by communication equipment to the reception of the said readings by an electric power company was calculated considering the use of the international standard protocol for automatic meter reading IEC 62056. (b) The limit of the number of waits for transmission dominantly influences the communication performance due to the random access scheme upon connecting to nearby equipment, and also the limit of the number of retries for transmission due to the radio interference from distant equipment upon connecting to faraway equipment.

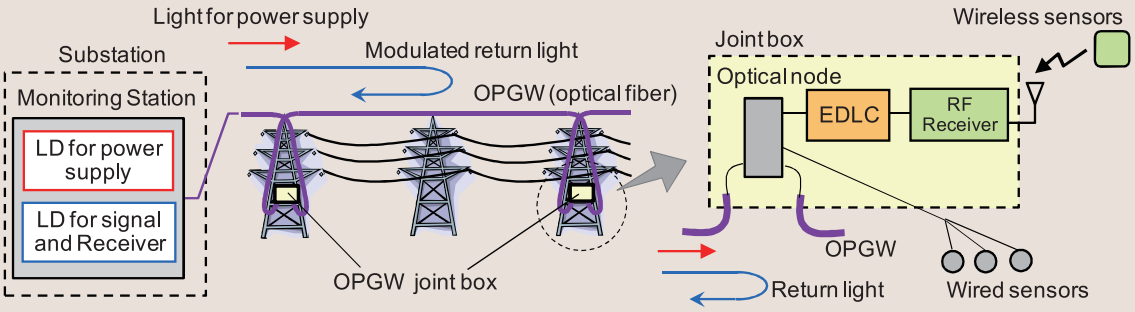


Fig. 2: Multi-point optical sensing system using remote optical power supply connecting to wireless sensors

The driving power of optical nodes is remotely supplied by a light source at the monitoring station, and no power equipment is necessary at sensing sites. Data from wireless sensors with large power consumption can be collected by driving the receiver in a short time using charged energy in EDLC (electric double-layer capacitor). Moreover, an efficient data collection method was achieved for simplex sensors that monitoring station surveys data sending timing of sensors and controls the timing to start the charging of EDLC.

Table 1: Examination of the time synchronism between master and slave clocks in combination with IP-related conventional communication equipment (A) and synchronization scheme-implemented one (B)

Since conventional wide-area Ethernet or IP network without time synchronization scheme implemented apply to actual wide-area networks, the applicability of communication patterns and synchronization schemes was examined from a regulation viewpoint and experimentally. Some cases showed the restriction of applicable synchronization schemes and the increase of time synchronization error to tens of microseconds or greater.

Synchronization scheme of B \ Communication pattern of A	1:1	1:n
Centralized operation	✓	✓
Peer to peer operation	–	#
None (Conventional only)	✓	✓

Legend ✓: Synchronization operable
–: Inoperable
#: Operable only for Ethernet

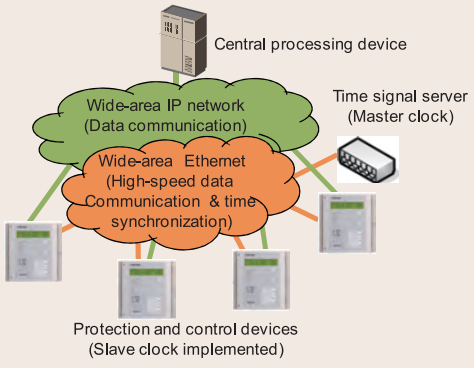


Fig. 3: Examination of the applicability of time synchronization scheme to stabilizing control system using wide-area IP-related communications

A network system for stabilizing control was constructed using communication equipment with time synchronization scheme implemented and protection and control devices with slave clocks. Even under heavy traffic conditions, the network maintained a time synchronization error of around 1μs (Contract research from NEDO).

Priority Subjects — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Evaluation of the Feasibility of Demand Response Suitable for Japan

Background and Objective

Recently, some electric utilities or demonstration projects of smart community have begun various attempts to utilize Demand Response (DR), such as encouraging peak shaving or load shift of electricity demand by electricity rate, as a form of experimental critical peak price. However, knowledge of participation rate for DR program, the amount of load shaving, or the degree of customers' response to rate change has not been sufficiently accumulated.
In this project, we assess the feasibility of DR as a new application for securing grid stability as well as peak shaving from a viewpoint of acceptability and cost benefit. We also supply useful information for electric utilities such as the possible variation in rate menu or service and global optimization of energy utilization including renewable energy.

Main results

1 A Field Test of DR Load Control in Japanese Office Buildings

We studied the customer-side costs, benefits and acceptance of automated DR (ADR) and manual DR (MDR) controls through a field test of such DR controls targeting an actual office building. MDR can control an air conditioning load in a more moderate way than ADR, due to the fact that office workers in MDR-controlled floors can manually set an acceptable office temperature themselves. The experiment results show that, ADR can control the electricity-consuming equipments with certainty but is very likely to decrease the subjective working efficiency of workers in the controlled area. On the other hand, variation in the load reduction of MDR can be seen. MDR may be a more cost-effective approach than ADR, though uncertainty of the MDR controls remains as an issue. (Y12025).

2 Possibility of Practical Use of Building Energy Management Systems (BEMS), Demand Monitors and Controllers to Demand Response in the Commercial and Industrial Sector

The possibility of BEMS, demand monitors and controllers to ensure demand curtailment in DR programs is discussed. Their usage for demand curtailment is classified into two types: I. customer collects electricity usage information, conducts the data analysis, and plans DR strategies prior to DR events, and II. customer prefers to take actions regarding DR strategies in response to a warning from BEMS, demand monitors or controllers (Table 1). BEMS, demand monitors and controllers play important roles in every step of DR activity. Applications such as transfer of DR signals with electricity suppliers and DR aggregators, and data analysis for planning DR contracts and strategies are promising (Y12022).

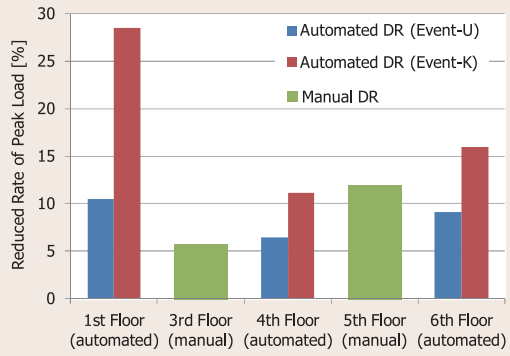
3 Applicability of Demand Response to Voltage Control in Distribution Systems with Large Integration of Photovoltaic Generator (PV)

Using our comprehensive analysis tool for power distribution systems, we quantitatively evaluated the possibility of implementing a DR program against the voltage rise problem in distribution systems with large integration of PV. According to our simulations, we must install DR with a PV penetration of more than approximately 30%. The operation days and times of DR increased in proportion with PV penetration rate, depending on the arrangement of loads and PVs. We found that with evenly distributed loads and PVs (Case1), the operation days and times were significantly less than if arranged on the end side of the distribution line (Case2). Furthermore, we calculated the costs which could be allocated to DR investment through comparison with conventional measurement (Fig. 2) (Y12008).

4 Issues Regarding Penetration of Home Energy Management System (HEMS)

We conducted a review of past demonstration projects on HEMS since 2001 and sorted out the remaining issues regarding penetration of HEMS. The most serious issues for market penetration are summarized as the following three aspects; uncertainty and continuity of energy saving, a high installation cost, and the level of understanding of customers toward energy saving (Table 2). It is important for the penetration of HEMS to solve these issues using various measures (such as auto-control device or continuous and effective information supply of energy saving) and to add further values to HEMS as well as fostering consumers' understanding, although its necessity or usefulness for customers are still uncertain (Y12011).

Other reports: (Y12018), (Y12021)



Event-K : Temperature is raised by 2ºC during 1PM-4PM automatically
Event-U : Temperature is raised by 1ºC during 1PM-4PM automatically
Manual DR : Degree is set manually by office workers during 1PM-4PM

Fig. 1: Reduced rate of peak load

This figure shows an experiment result for a six-storied office building in Yokosuka City. Only 1st floor uses non thermal-storage type air conditioner, therefore its reduced rate is larger than the others. Among the floors using the storage type air conditioners, the reduced rates are consistent with the raised width of temperature settings for automated DR, however, they are different by the floor for manual DR. The interview survey for office workers suggests automated DR decreases the subjective working efficiency more than manual DR, although they may not be comparable directly because the temperature can be changed for manual DR.

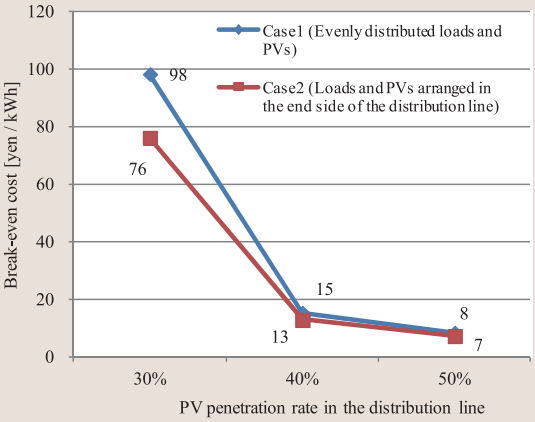


Fig. 2: Maximum expense for the DR program

Economic Benefit (Break-even cost)

$$= \frac{\text{The avoided cost by implementing DR}}{\text{The reverse power flow which must be reduced by DR}}$$

A break-even cost is the cost of the distribution system (Static Var Compensators) which can be avoided by implementing the DR program, that is, the maximum expense for the DR. It is useful for judging whether installation of a DR program is cost-effective.

Table 1: Classification of usage of BEMS, Demand Monitors and Controllers in Electricity Demand Curtailment after the Great East Japan Earthquake

Our interview survey (111 accounts) and postal questionnaire survey (3,031 accounts) for C&I customers, reveal the usage of BEMS, demand monitors and controllers for DR activities. The interview survey shows that the difference of usage of BEMS, demand monitors and controllers though their kW demand reductions was as large as 25% at a mode.

Type	Description	Example of Answers
Before-warning type	Preparing demand reduction strategies acted before the warning from demand monitor	We have learned to curb the warning through the adjustment process of air-conditioner's operation for electricity saving. (large customer, communication infrastructure constructor)
After-warning type	Preparing demand reduction strategies acted after the warning from demand monitor	We made demand reduction strategies in the summer of 2011. Automatic and manual actions were taken after the warning. (large customer, electronics devices manufacturer)
Irrelevant type	No connection between demand reduction and demand monitor	We already have achieved 40% energy conservation, so the warning can not be sounded. (small customer, retail)

Table 2: Issues regarding penetration of HEMS, and current evaluation results for resolving the issues

○ : Has been resolved or will be resolved in the near future/
△ : Resolved/ × : uncertain
※ Because we sorted out the issues from the viewpoint of customers, we excluded communication standards.

Issues		Contents	Evaluation
Effect of energy saving		There is the dispersion, but around 10% of energy saving effects are anticipated on the average. However, all is an effect by the HEMS or is opaque. The continuity of the effect is uncertain, too. It is an urgent problem.	△
Cost/advantage	High installation cost	High installation cost compared with the required pay back years and the willingness-to-pay	×
	Installation in existing house	Burden of wiring work/Introduction cost stands out.	×
	Advantage for consumers	Uncertain advantage/ effective public relations	×
	Value added service	Attractive killer contents	×
	Business model	Establishment of business model	×
Level of understanding of consumers for energy saving		To improve energy saving consciousness /proactive behavior/continuity	×
Technology /function	Comfortableness	Customizable	○
	User-friendliness	User-friendliness	○
System	Assist	Subsidy	○
	Protection of personal information /cybersecurity	Fear of leaking of personal information/ fear of appliances breakdown and fire by wrongful control	△

Development and Evaluation of Advanced Heat Pumps

Background and Objective

Heat pumps are attracting attention in and outside Japan as an effective technology to promote energy conservation and reduce CO_2 emissions. Much research and development is carried out to improve efficiency, use low-GWP (global warming potential) refrigerants, and expand applications to a wide variety of thermal demand.

In this project, we aim to develop and evaluate highly efficient, compact, and low-priced heat pumps using low-GWP refrigerants for residential hot water supply, room heating, industrial drying and so on. We contribute to launching and popularization of heat pumps which are attractive to the end users on the market.

Main results

1 Development of high-efficient heat pumps using low-GWP refrigerants

Some residential heat pumps use HFC (hydro-fluoro-carbon) refrigerants as a substitute for fossil fuel boilers and electric boilers of central hot-water room heating systems* in cold regions. However, these are not widespread due to their very low heating capacity and COP (efficiency of heat pump defined as heating capacity divided by electric power consumption) at lower outside air temperatures, and the difficulty to achieve hot-water temperature over 70℃ required by central hot-water room heating systems due to the characteristics of HFC refrigerants.

In collaboration with Hokkaido Electric Power Company and SANDEN Corporation, we have developed a new residential heat pump for hot-water room heating, using CO_2 refrigerant and a cascade cycle that enables high heating capacity and COP in cold regions. The new system was launched on the market in May, FY2012 (Fig. 1).

2 Evaluation of the annual performance of residential heat pump water heaters

We have evaluated the annual performance of some residential heat pump water heaters using our test facility with the aim of setting a standard to promote energy conservation and reduce CO_2 emissions. We have collected the data of heating capacity, COP and so on, considering the effects of outside air temperature and humidity and hot water demand depending on the region, season, lifestyle and family structure of end users, etc. To improve heat pump efficiency, we have also developed and verified a method to simulate water temperature distribution and profile in the hot water tank considering hot water feed from the heat pump unit, hot water supply from the tank, and heat loss from the tank surface based on experiments (M12003).

3 Installation of a New Heat Pump Test Facility

We have designed, manufactured and installed a new unique test facility for development and evaluation of heat pumps in commercial and industrial use such as a steam generating heat pump in heating process and a hot air generating heat pump in drying process. The full-scale operation of this facility will start in the second half of FY2013 (Fig. 2).

* Systems which are a combination of hot-water panels within a house and a hot-water generating machine outside a house. These systems have been gaining popularity in cold regions due to their high comfort factor and safety.

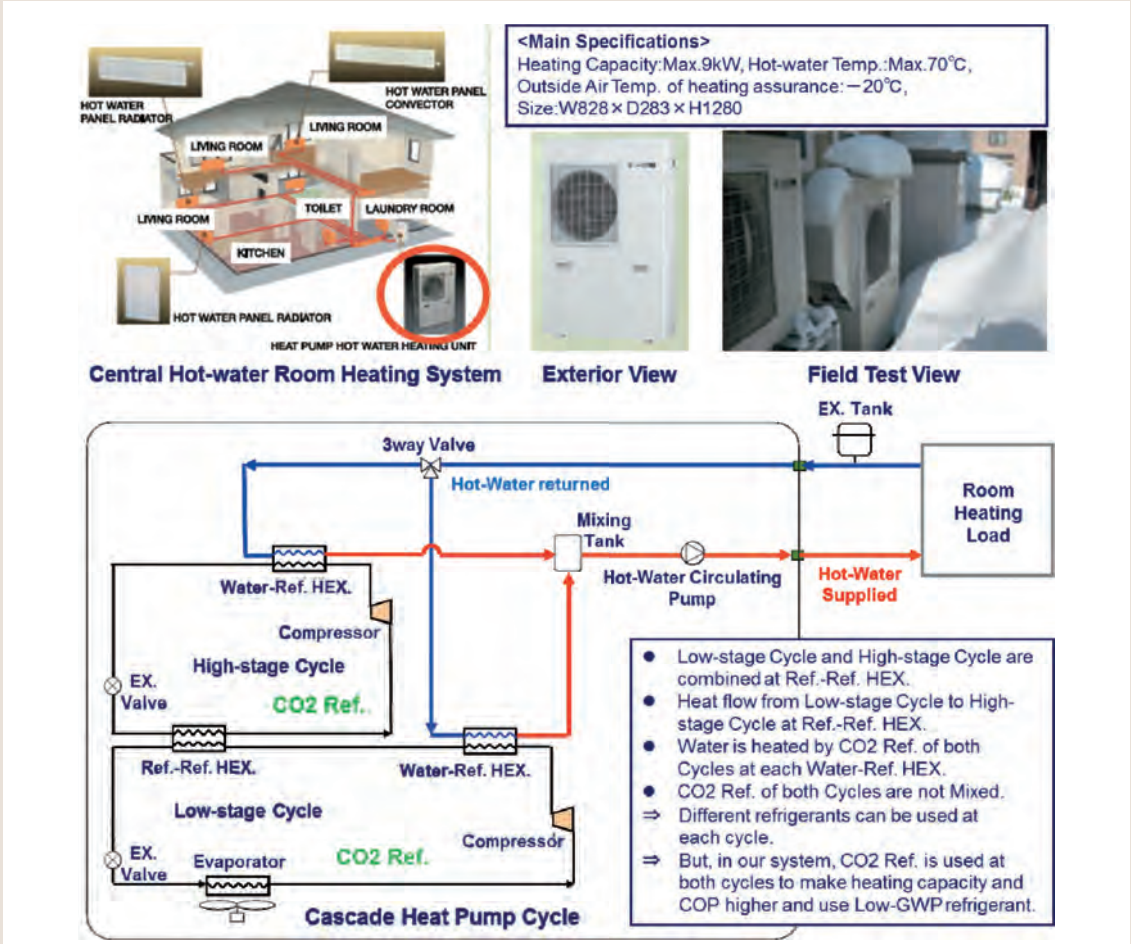


Fig. 1: New residential heat pump for hot-water room heating using CO_2 refrigerant

SANDEN Corporation started sales in May, FY2012. Product's name is "ecoruno".

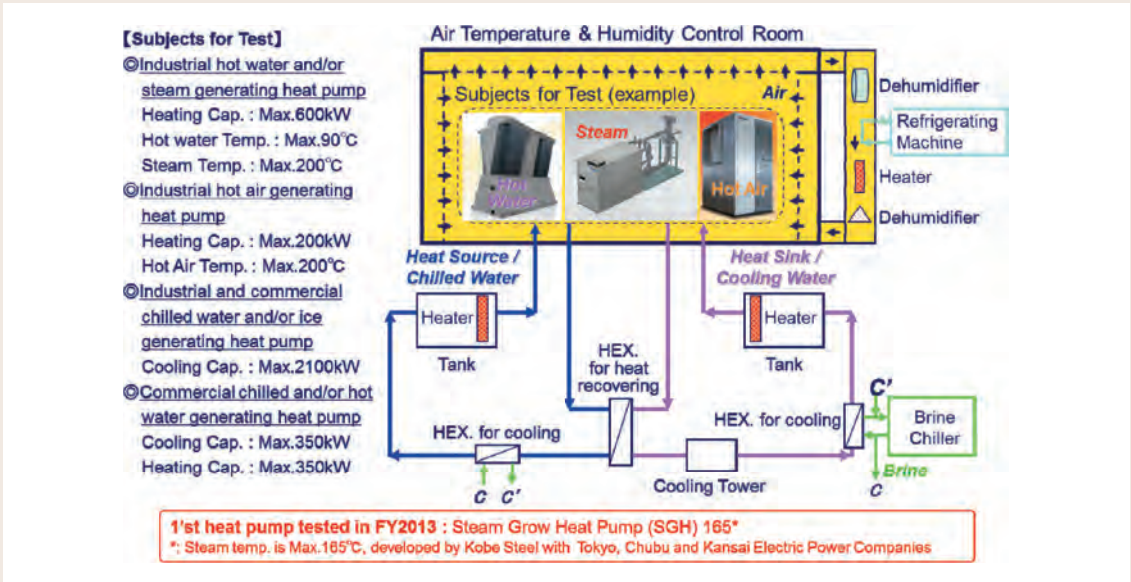


Fig. 2: New test facility for development and evaluation of heat pumps in commercial and industrial use

Full-scale operation will start in the second half of FY2013.
Photo: (left) CAONS by Toshiba Carrier, (Center) SGH by Kobe Steel, (Right) Eco Sirocco by Mayekawa.

Priority Subjects with Limited Terms — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Development of High-Performance SiC Power Semiconductors

Background and Objective

Development of low-loss high-voltage power conversion equipment is expected for stable power supply under mass introduction of renewable energy sources and in response to reinforcement of grid interconnection and wide-area integrated operation. Silicon carbide (SiC) power devices are potential technology to realize small-sized low-loss power conversion equipment, although practical applications of the devices are limited to low-power equipment such as air conditioners. Thick SiC crystal layers with a low defect density are essential for the development of large-capacity devices. We have obtained thick and high-purity SiC crystal layers able to accommodate very high voltage (>13 kV) devices in the use of an original SiC crystal growth reactor.

In this project, we aim to establish a practical crystal growth technology for the production of thick SiC crystal layers with a low defect density which realize high-voltage, large handling current SiC power devices.

Main results

1 Optimization of the fast SiC crystal growth process

We developed a fast SiC crystal growth (epitaxial growth) technique achieving a low defect density*1 to obtain thick, high-quality SiC crystal layers for high-power SiC devices. It was clarified that lowering the partial pressure of Si source gas (SiH_4) as well as adding HCl to the gas system prevent the formation of stacking faults in the crystal growth process even at a high growth rate exceeding a few tens of microns per hour (Fig. 1). At the same time, reductions of dislocations and point defects are achieved simultaneously by adjusting the crystallographic angles of the substrates. Based on the improvements, the densities of stacking faults and dislocations are reduced to a level which can realize large devices with ~1 cm^2 area (equivalent to >100 A class), and high-quality SiC epilayers are attained with a point defect density low enough to obtain long carrier lifetimes*2 for very high voltage devices with a application of "Carbon Interstitial Diffusion Process"*3 (CRIEPI's original process).

2 Clarification and control of dislocation behavior for improvement in quality of SiC crystal layers

We clarified dislocation behavior and development of defect imaging techniques, aiming to prevent the degradation of electrical performance of SiC devices by controlling dislocations in SiC crystals. It was clarified that increasing the annealing temperature or performing ion implantation followed by the second epitaxial growth before Ar annealing in "High-Temperature Dislocation Conversion Process" *4 (CRIEPI's original process) achieves a significant reduction in the BPD density of SiC crystal layers by enhancement of conversion ratios of basal plane dislocations (BPDs) to threading edge dislocations (TEDs) (Fig. 2). We also succeeded in discriminating the Burgers vector*5 of TEDs using plan-view photoluminescence (PL) imaging and direct observation of line directions of TEDs and threading screw dislocations (TSDs) by cross-sectional PL imaging (Figs. 3 and 4). These defect imaging techniques can accelerate further improvements in quality of SiC crystal layers for the development of high-performance SiC devices through more precise control of TED and TSD propagation behavior.

*1 In this study, 8H-type stacking faults, BPDs and point defects ($Z_{1/2}$ center), which degrade the electrical performance of SiC devices, are reduced to 0.1 cm^{-2}, 0.09 cm^{-2} and $1x10^{12}$ cm^{-3}, respectively.
*2 Carrier lifetime: decay time of excess electrons and holes to recover the thermal equilibrium. A longer carrier lifetime achieves low-loss current conduction of SiC bipolar devices.
*3 Carbon Interstitial Diffusion Process: a method to eliminate carbon vacancy defects by introduction of carbon interstitials from SiC crystal layer surface followed by thermal diffusion of the interstitials to deep in the layer.
*4 High-Temperature Dislocation Conversion Process: a method to convert BPDs to TEDs by high-temperature annealing in Ar at 1800-2000℃, while BPDs degrade forward current conduction performance of SiC bipolar devices and TEDs are inactive for the degradation.
*5 Direction of disorder of atomic arrangements around a dislocation line.

This research is partly supported by the Japan Society for the Promotion of Science (JSPS) through its "Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program)".

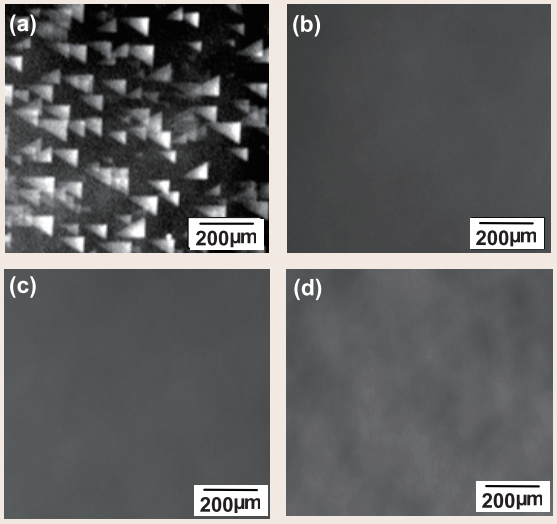


Fig. 1: PL mapping images of SiC crystal layers

PL images of 4H-SiC crystal layers obtained under (a) system pressure of 40 Torr, H_2 flow rate of 40 slm, (b) 40 Torr, H_2 60 slm, (c) 30 Torr, H_2 40 slm, and (d) 200 Torr, H_2 40 slm with the addition of HCl at 3 slm. The PL images were acquired using a 450 nm band pass filter. Triangular defect contrast observed in (a) corresponds to 8H-type stacking faults in the crystal layer, and no 8H-type stacking faults are found in (b), (c) and (d). [slm: standard liter per minute (gas flow rate under the standard temperature and pressure)].

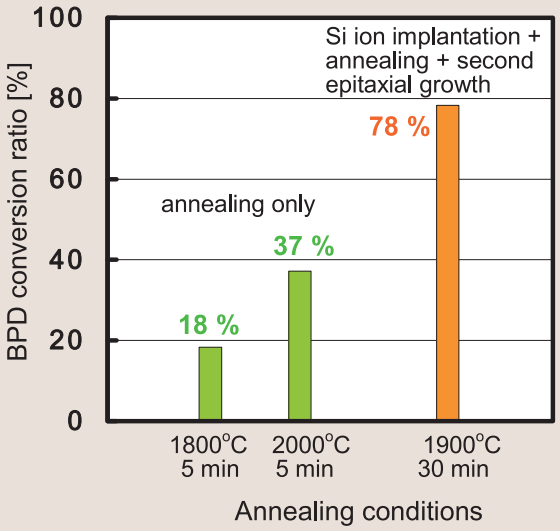


Fig. 2: Conversion ratios of BPDs in "High-Temperature Dislocation Conversion Process"

Conversion ratios of BPDs in "High-Temperature Dislocation Conversion Process" are enhanced by an increase of annealing temperature or performing ion implantation to the layer surface followed by high-temperature annealing and the second epitaxial growth, and a significant reduction of a BPD density in SiC crystal layers is achieved.

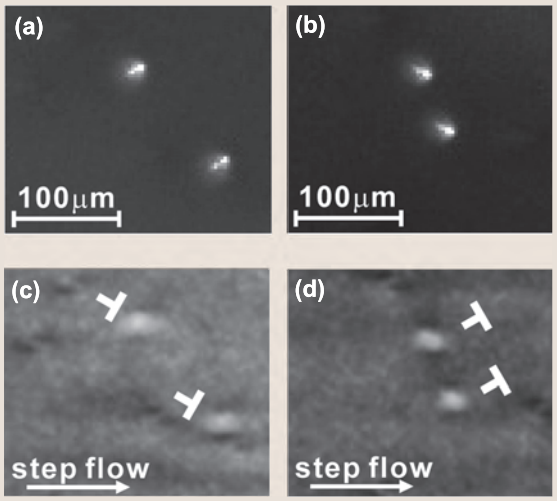


Fig. 3: (a), (b) Plan-view PL images and (c), (d) synchrotron X-ray topography images of TEDs with the two types of Burgers vector

The PL images in (a) and (b) were taken using a 900 nm band pass filter. The "⊤" signs in (c) and (d) indicate the direction of an extra half plane created by a TED, where the direction is identified by the synchrotron X-ray topography images. The PL appearance of the TEDs in (a) and (b) is confirmed to vary according to the direction of an extra half plane, demonstrating the capability of discrimination of the extra half plane of TEDs in 4H-SiC crystal layers by the PL technique.

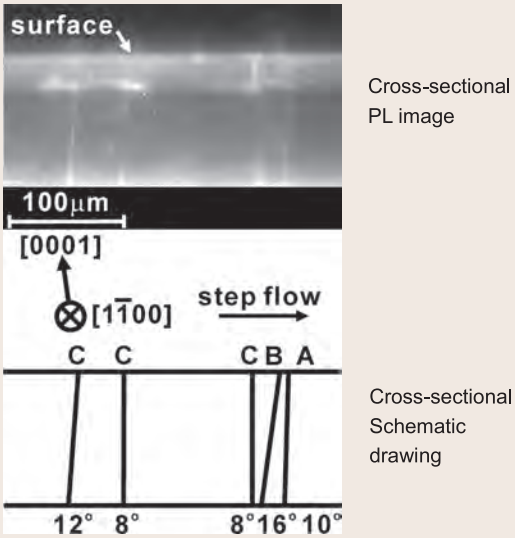


Fig. 4: Cross-sectional PL image of a 4H-SiC crystal layer and schematic drawing of the image

The "A" and "B" lines correspond to TEDs and the "C" line corresponds to a TSD, and the angles indicate the inclination angle from [0001] direction in the schematic drawing. Direct observation of the behavior of TEDs and TSDs propagating toward the surface with an inclination angle in a thick SiC crystal layer is demonstrated.

Priority Subjects — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Establishment of Evaluation Technologies for High Performance Secondary Batteries

Background and Objective

A large scale secondary battery system is expected to be used for leveling operation in grid systems with renewable power generation such as photovoltaic and wind power generation. It is important to evaluate the life of the battery in order to operate such secondary battery systems for long periods of time.

In light of this, we clarified the degradation mechanism of the lithium-ion battery, which is expected to have high energy density and high energy efficiency. The methods are novel techniques in order to measure each electrode's behavior and postmortem analysis techniques in order to establish the non-destructive and accurate evaluation of battery performance. In addition, we investigate an advanced battery for the potential of improving safety and production cost compared with the conventional lithium-ion battery.

Main results

1 Development of a measurement method of electrode behavior during capacity fading of the battery using a pseudo reference electrode

In the lithium-ion battery, the cathode and anode potential changes during charge and discharge, and the obtained voltage of the lithium-ion battery is different from both the cathode and anode potential; thus, it is difficult to obtain the profile of each electrode potential from measurement of the cell voltage. Therefore, we could not obtain useful information about the determining factors of the capacity fading from each electrode profile. As such, we proposed a method to introduce a pseudo reference electrode, which shows stable and constant potential and no significant influences on cell performance (Fig. 1). We introduced the proposed pseudo reference electrode to the all-solid-state lithium ion cell manufactured by CRIEPI, and confirmed a long stable operation of over 500 cycles (over 1 year). The rise in cathode potential at the end of discharge and the decrease of the low potential region of the anode were observed using a pseudo reference electrode (Fig. 2).

2 Analysis of the capacity fading mechanism through cell disassembly

Commercially available lithium-ion batteries (manganese oxide based cathode, graphite based anode) were disassembled after capacity fading and the half cells were reconstructed with the extracted cathode and anode using lithium metal as a counter electrode. Both reversible capacities were measured and compared with the original cell capacity in order to clarify the capacity fading mechanism. Moreover, quantitative lithium consumption in anode was measured using chemical analysis. These actions made it possible to estimate the change in reversible capacities and the operation region of the cathode and anode. As a result, we found that the cathode operation region decreased* with the rise of the cathode potential at the end of discharge due to the irreversible consumption of the lithium at the anode. In addition, we confirmed that the acceleration of the capacity fading of the cell in high temperature operation derived from the degradation of the cathode while the degradation of the anode exhibited little influence on the capacity fading of the cell (Fig. 3). In conclusion, the capacity fading of the cell could be explained by decreasing of the operation region of the cathode and degradation of the cathode active material.

3 Development of a low cost all-solid-state Na battery with reliable safety

Na batteries, which use Na ion instead of Li as a mobile ion species, have the potential to be applied to various kinds of cathode crystalline structures. Na as an element has lower resource restriction than Li. We investigated the possibility of developing an all-solid-state Na battery, which has more potential of improving safety compared with the conventionally used flammable organic electrolytes. The demonstrated cell, which consisted of $NaCoO_2$ cathode and Na metal anode, showed results as per the designed initial charge and discharge capacity (Fig. 4). In addition, we confirmed the viable use of Ni and Fe oxides as cathode material instead of resource restricted Co. Therefore, we demonstrated that the proposed all-solid-state Na battery has potential as a low cost battery system with reliable safety.

* The capacity operation region depends on the operation voltage between charge and discharge. When the cathode potential at the end of discharge increases, the potential gap between the end of charge and discharge becomes small, and operation region becomes narrow. This causes capacity fading due to the decrease in mobile lithium ion inside the cell.

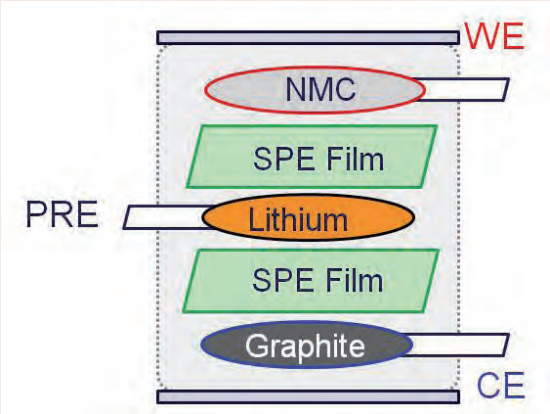


Fig. 1: All-solid-state lithium-ion battery with pseudo reference electrode

Isometric lithium metal (pseudo reference electrode: PRE) was introduced in the location of between cathode ($LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$: NMC) as a working electrode (WE) and anode (Graphite) as a counter electrode (CE). Long term uniform electrochemical reaction was demonstrated using PRE. Each electrode potential and interfacial impedance can be monitored by the proposed cell configuration.

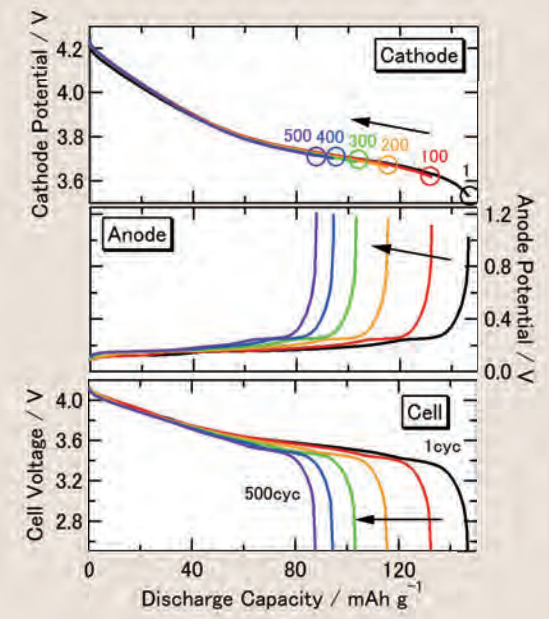


Fig. 2: Cathode and anode potential variation during charge and discharge cycle operation

Voltage profiles of each electrode in the proposed all-solid-state lithium-ion battery using a pseudo reference electrode were successfully demonstrated over 500 cycles (over 1 year). We confirmed that the cathode potential at the end of discharge rises with the capacity fading of the battery.

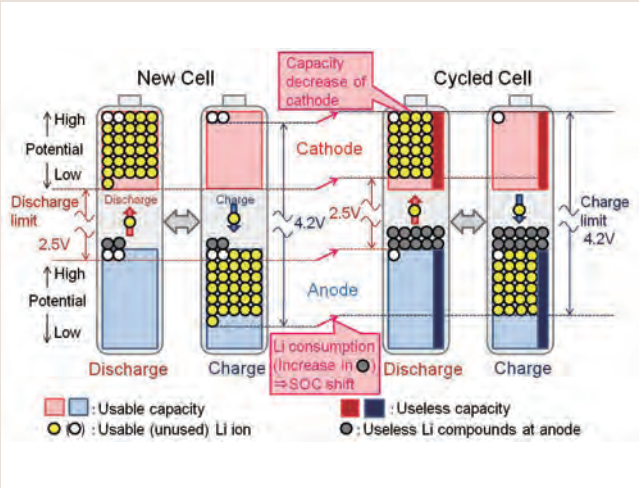


Fig. 3: Capacity fading mechanism presumed from the cell disassembly

The reversible capacity of lithium-ion battery is determined by the number of usable active lithium-ions (●) between electrodes supplying from the cathode. We confirmed that the capacity fading of the battery can be explained by the irreversible consumption of Li at the anode (increase in ●) and the degradation of the cathode (increase in useless inactive capacity of the cathode, ■). The increase in the cathode potential at the end of discharge with capacity fading of the battery was explained as follows. The increase of the irreversible Li at the anode was larger than the degradation of the cathode active material. As a consequence, the decrease in the number of Li-ion triggered the increase in rise of the cathode potential at the end of discharge.

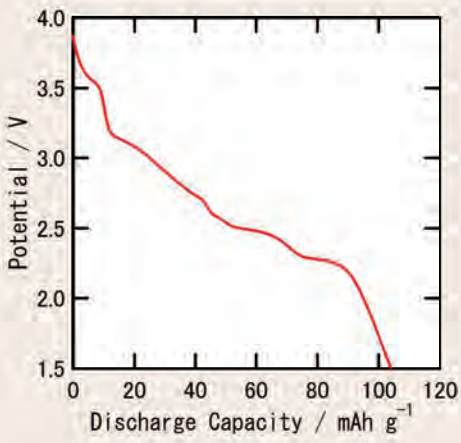


Fig. 4: Discharge voltage profile of prepared all-solid-state Na battery

The prepared all-solid-state Na battery consisted of $NaCoO_2$ cathode, Na metal anode, and solid polymer electrolyte (SPE) demonstrated near the designed discharge capacity ($110mAhg^{-1}$) at 60°C.

Priority Subjects — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Evaluation of Energy Efficiency in Commercial Kitchens

Background and Objective

Commercial electric kitchens are becoming widespread, for the reason that they do not use exhaust combustion gas, emit less radiant heat, and are highly energy efficient. They can also contribute to energy-saving and reduction in indoor thermal environmental impact. However, the effects of energy-saving and size reduction on air conditioning systems for kitchens are not fully taken advantage of as the required ventilation air volume is currently regulated to conform to gas-fired kitchens.
In this project, we discover the adequate ventilation in an actual commercial kitchen, which does not lead to uncomfortable hotness, condensation, or an unpleasant smell. Moreover, we investigate the relationship between capture efficiency of exhaust hoods and air disturbance deriving from the cooker's movement or from air-conditioner.

Main results

1 Assessment of Ventilation Performance and Energy-Saving Effects of Reducing Ventilation in Commercial Kitchens

We have carried out an examination in an actual commercial electric kitchen in which the amount of ventilation changes between three values, 0.25m/s, 0.20m/s and 0.15m/s at a face velocity on an exhaust hood opening. The results of a questionnaire targeting the worker showed that changing the ventilation amounts had no clear difference on thermal comfort, condensation, and unpleasant smells in the kitchen, even in case of 0.15m/s which is half of design standard value*1 (See Fig. 1). Furthermore, we calculate the amount of annual energy-saving using a heat load simulation. The energy-saving effect was calculated to be 60% for ventilation and 11% for air-conditioning (See Fig. 2). (R12001)

2 Relationship between capture efficiency of exhaust hood and air disturbance derived from the cooker's movements

We investigated the capture efficiency of an exhaust hood while using a fryer and a noodle cooker. The capture efficiency for the fryer and noodle cooker is 92% and 93% respectively (See Table 1). Meanwhile, the respective capture efficiencies without air disturbance are 97% and 98%. The capture efficiency decreases 5 points due to air disturbance. This suggests that there is no remarkable reduction in the capture efficiency due to the air disturbance derived from a person's movement while cooking. (R12003)

3 Relationship between capture efficiency of exhaust hood and downward air current in front of the exhaust hood derived from an air diffuser

We developed equipment which is able to generate imitated downward air flow and control air flow velocity in front of an exhaust hood. We investigated the capture efficiency of the hood when the air flow velocity is changed as a parameter on a fryer and a noodle cooker. Provided that the downward air flow velocity is less than 0.4m/s, there is no remarkable reduction in the capture efficiency for both the fryer and the noodle cooker (See Fig. 3).(R12011)

*1 Design standard value of ventilation is 0.3m/s at a face velocity on an exhaust hood opening.

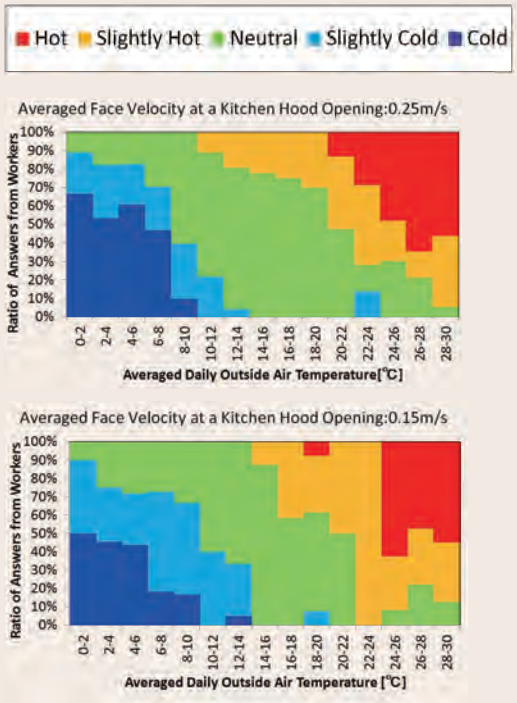


Fig. 1: Influence on thermal comfort by reducing ventilation amount

There was no clear deterioration of thermal comfort observed due to changes in the amount of ventilation, even in case of 0.15m/s which is half of standard value.

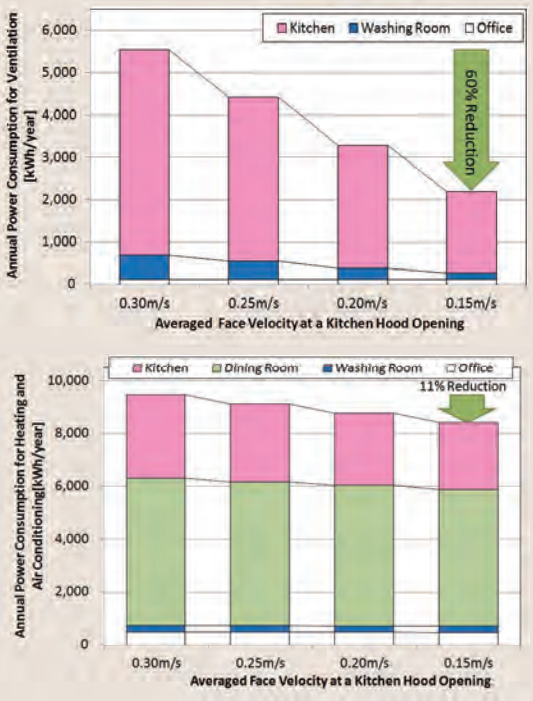


Fig. 2: Energy saving effect for ventilation (upper) and for air conditioning (lower) by reducing ventilation amount

The energy saving effects of reducing the ventilation amount to 0.15m/s, or half the standard value, were found to be 60% for ventilation and 11% for air-conditioning.

Table 1: Capture efficiency of exhaust hood while cooking

The capture efficiency on an electric fryer and an electric noodle cooker are 92% and 93% respectively.

Cooking Appliances	Cooking Behavior	Capture Efficiency	
		While Cooking	No Air Disturbance
Fryer	Tempura Cooking	92%	97%
Noodle Cooker	Boiling Noodles	93%	98%

Cooking tempura

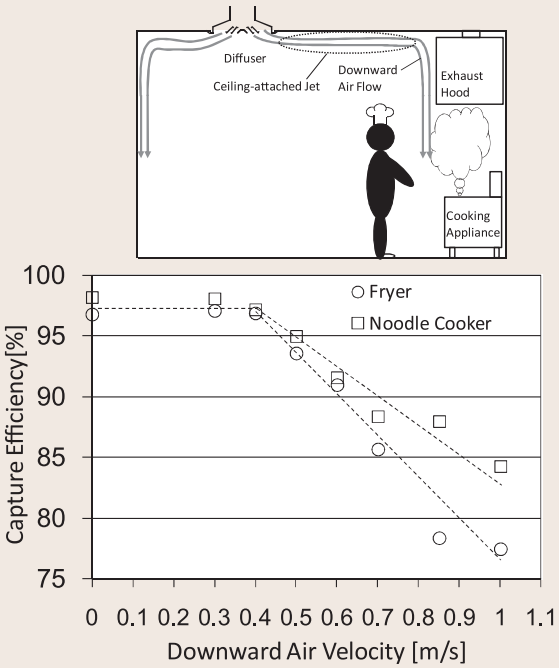


Fig. 3: Relationship between capture efficiency and downward air velocity in front of exhaust hood

Provided that the downward air flow is less than 0.4m/s, there is no remarkable reduction in capture efficiency of exhaust hood.

Priority Subjects — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Acceleration of Electrification with Electric Vehicles and Secondary Battery Systems

Background and Objective

As countermeasures to global warming issues, the introduction of a low carbon electric power supply and promotion of energy-saving are important. The electrification of the public welfare and transportation sectors, which increase energy consumption and carbon dioxide emissions, is effective for energy-saving. In this project, a policy is proposed for acceleration of popularization of electric vehicles (EV) and charging technologies are developed to provide safety and high performance in the transportation sector. Moreover, a hybrid energy storage battery system with a heat pump hot-water supply system for residences is proposed in the name of electrification in the public welfare sector involving utilization of secondary battery technologies.

Main results

1 Expansion of a layout optimization model for EV charging infrastructure

In a questionnaire on EV/PHV (plug-in hybrid cars) targeting residential users, "Too short mileage per each charge", "Not enough charging equipment on roads and in cities", etc. are mentioned as points of dissatisfaction (Y12029). Therefore, we have developed a driving range model to exhibit the area where EVs can reach using a EV driving mileage simulation code, and have established a layout optimization model for EV charging infrastructure by utilization a traffic simulator. In the layout optimization model for EV charging infrastructure, we expanded the function to take into account the effects of increasing energy consumption and recharging by regeneration when an EV goes up and down a mountain road respectively, which inputs altitude information on road map data. Consequently, it was clearly shown that there was a need to install quick charging stations a high density in mountainous areas. Furthermore, we estimated the optimum layout of quick charging stations, and summarized the installation priority of quick charging stations as (a) major city area, (b) major urban area, (c) trunk roads interconnecting cities, and (d) peninsula areas or high altitude areas. Figure 1 shows the result of an optimum layout of quick charging stations using a traffic simulator in Okayama and Tottori prefectures*1.

2 Develpment of a bi-directional inductive charging technology

A bi-directional magnetic-resonant power transfer setup was developed, whereby the secondary circuit had the same inverter as the primary one. The setup was a combination of four spiral coils and inverter assemblies used in commercial hybrid electric vehicles (Fig. 2). By increasing a voltage up to 429 V with a boost converter included in the primary assembly, the setup delivered a DC power boost to 1.5 kW with power efficiency*2 of 71 % although the coupling coefficient between the primary and secondary circuits was only 0.1. Since a calculation model including internal-resistors of the coils was in good agreement with the experimental results, we concluded that a Joule heat emitting from the coils mainly determined the transfer loss (Fig. 3).

3 Hybrid energy storage battery system with a heat pump hot water supply system for residences

We developed a time-shift control method for a residential hybrid energy storage battery system with a heat pump hot-water supply system. This method is effectively used for improving the COP (coefficient of performance) of heat pumps by practical application of outside and water temperatures, and for suppression of radiation energy losses from the hot water tank. We constructed a simulation program for the estimation of year-round effect of energy-saving by our residential hybrid energy storage battery system under several conditions with load-pattern data of hot water supply and outside temperature data. We verified the estimation data in comparison with the experimental data of our prototype system, subsequently providing it as an estimation tool.

*1 This study of "Analysis on Optimum Layout of EV Charging Stations (2013)," is supported by Next Generation Vehicle Promotion Center.
*2 (Power Efficiency) = (The secondary DC power) / (The primary DC power)

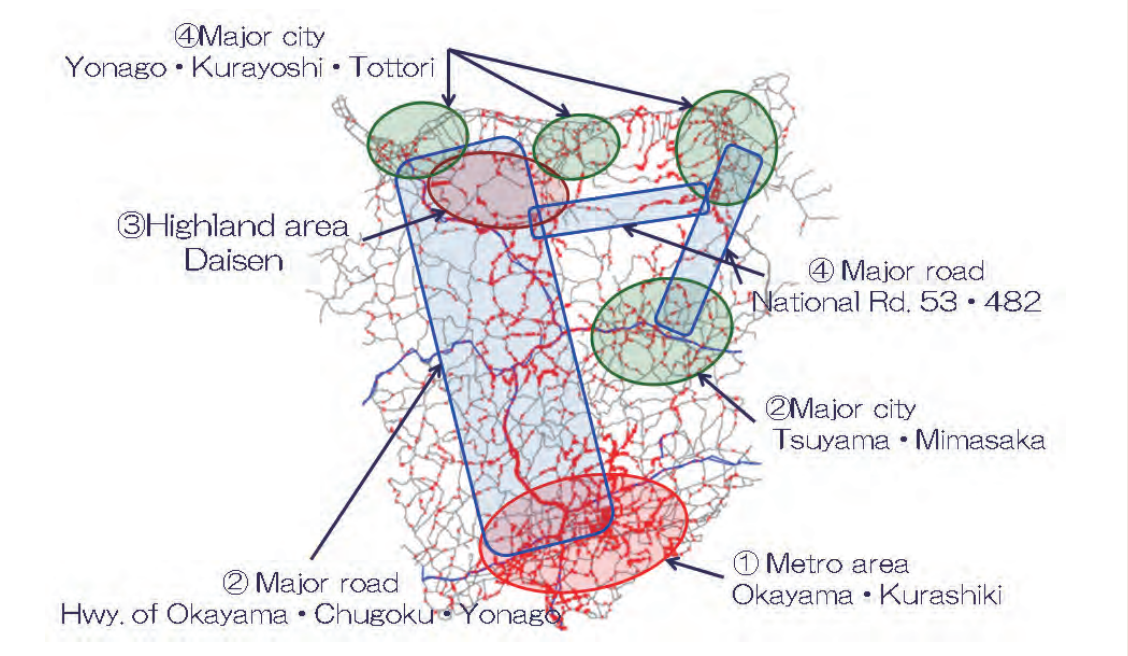


Fig. 1: Result of an optimum layout of quick charging stations by a traffic simulator in Okayama and Tottori prefectures

Using a traffic simulator in Okayama and Tottori prefectures, we analyzed the optimum layout of quick charging stations which prevents EV batteries from running flat. It turned out that in order to install quick charging stations, the 1st installation should be in the major city of Okayama, the 2nd along the trunk road of Okayama-Chugoku-Yonago highway, and core cities of Tsuyama and Mimasaka, the 3rd to the Daisen mountain area, and the 4th to the core cities of Yonago, Kurayoshi, and Tottori.

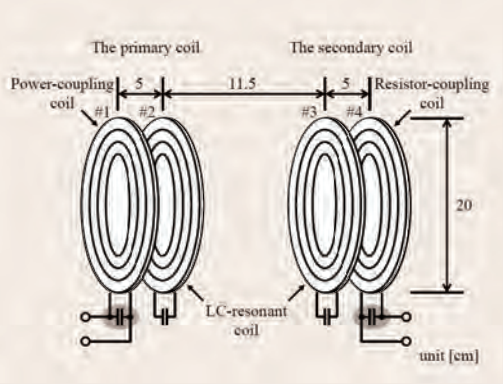


Fig. 2: Alignment of high-frequency coils for bi-directional magnetic-resonant power transfer

By using four spiral coils, the transferring circuit had a series of three transformers. Coupling ratios between the first and the second coil, and between the third and the fourth coil were 0.2. Coupling ratio between the second and third coil was 0.1. Thus the symmetry circuit assured a bi-directional power transfer.

*(Coupling ratio) = (Mutual inductance)/(Self inductance)

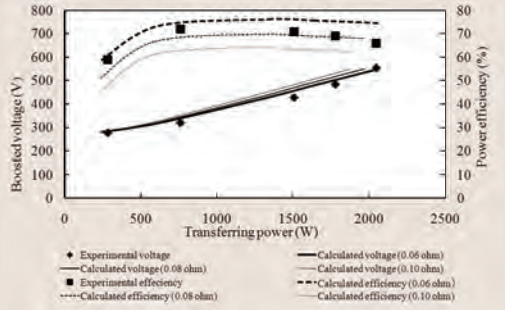


Fig. 3: Boosted voltages fed into the primary inverter and efficiencies measured at different power transfers

By increasing the voltage up to 429 V with a boost converter included in the primary assembly, the setup delivered a DC power boost to 1.5-kW with an efficiency of 71%. A calculation model including internal-resistors of 0.08-ohm was in good agreement with the experimental results.

Basic Technology Subjects

Socio-Economic Research Center

Brief Overview

While changes in consumer behavior often lead to technological innovations and advances, the reverse is also true. Researchers in the electric power industry have to be mindful of the co-dependency that exists between consumer behavior, technological innovation and institutional changes. The Socio-Economic Research Center now covers various fields of expertise: economics, business administration, jurisprudence, psychology, physics, urban engineering, electric and nuclear engineering. The Center carries out research based on its solid academic expertise as well as observation of the facts and practices of the electric power industry.

Achievements by Research Theme

Utility Management and Policy

Aiming at revealing desirable institutional designs for the electric utility industry after ongoing utility reforms, the team attempts to develop analytic methodologies and presents implications in terms of management strategies, future growth opportunities and resources required for those changes.

- In order to reinforce LNG procurement, the factual state of affairs on the bargaining power of LNG was investigated based on interviewing practicians from LNG trades. Major findings included that opportunities to negotiate price are limited solely to when LNG projects are launched. Therefore, strategic joint procurements up to the quantity justifying a production train may be effective (Table 1). (Y12006)
- Via questionnaire surveys conducted in August 2012 targeting the general public in the Tokyo metropolitan area and academic professionals in biotechnology, nuclear energy technology and nanotechnology, which were then compared with a equivalent survey in 2009, we showed that risk perception of nuclear power generation has arisen not only amongst the public but also nuclear experts. The opinion of the public has changed to place more emphasis than before on the perspectives of 'a societal necessity' and 'possibility to prevent negative environmental impact' when they evaluate nuclear power generation. (Y12010).

Economic and Social Systems

We aim to provide useful information for the management planning of Japanese electric utilities by clarifying quantitatively and objectively the influences of conditions such as unstable electricity supply and increasing electricity generation costs on the Japanese economy, energy and electricity markets and utility companies management.

- We present an outlook for the Japanese industrial and energy structure up until 2030, following the report (Y12001) of an outlook for the Japanese macro economy. In the reference case based on the assumption of a moderately weak yen and stable overseas economy, the average annual growth rate of real GDP up until 2030 will be 1.1%. The total electricity demand will grow annually by 0.4% during the same period. In the "No-restart" case that the zero nuclear generation situation is maintained during the next two decades, the accumulated GDP loss amounts to 86 trillion yen toward 2030 (Fig. 1, 2). (Y12033)
- We measured the regional price elasticity of electric light and power demand within the regional jurisdictions of nine power companies, excluding Okinawa Electric Power Company. The price elasticity of electric power denotes the percentage change in power demand when the cost of electric power changes by 1%. An important issue for electricity business management is to know how the demand for power will change when electricity costs are increased by electric power companies. The results of an empirical analysis reveal that the values for price elasticity of the electric light demand in each region are distributed between 0.856 (Hokkaido) and 1.563 (Hokuriku); therefore, it is clear that price elasticity significantly varies from zero in all regions. Furthermore, since the price elasticity values of the electric power demand are between 0.158 (Tokyo) and 0.551 (Hokuriku), it is apparent that these values also significantly vary from zero in all regions. Therefore, we can confirm that the impact electric price hikes on electric power demand due to is not minor. Furthermore, this study showed that if we grasped only the price elasticity across the country as in the past, we would not be able to cast exact demand outlooks in each region (Y12015).

Energy Technology Assessment

While rebuilding a new set of methodology of energy technology assessment in the new era after the Great East Japan Earthquake, the team strives to support a reliable electricity supply in a sustainable manner.

Achievements by Research Theme

- Based upon the experiences with the accident of Fukushima Daiichi Nuclear Power Station, a comprehensive review of nuclear emergency preparedness is ongoing. Focusing on the French cases where the Local Information Commissions (CLI) plays a critical role, we examined how to improve stakeholder involvement and thereby derived concrete lessons for Japan. (Y12013).
- Large-scale commercial solar photovoltaic (PV) generation systems at 1, 2, 5 and 10 MWe to be built in Japan were assessed in terms of life-cycle CO_2 emission per kWh generated (LC-CO_2) by life-cycle assessment (LCA) method. As the main results, the LC-CO_2 of those grid-connected PV plants turned out in the range of 58~59g-CO_2/kWh, 52~55% higher than those of small scale residential systems at 38g-CO_2/kWh. (Y12031).

Table 1: An Assessment of LNG buyers' bargaining power

On the buyers' side in the LNG trading, opportunities to negotiate price are limited practically to when LNG projects are launched. Despite this limited chance, LNG buyers can still reinforce bargaining power when they have acquired measures for substitutional supply of LNG or of other energy resources. While purchases in large quantities are not necessarily effective in LNG trading, it is advantageous for buyers to choose a volume to reinforce bargaining power in the most effective manner, such as a quantity which justifies launch of a unit of production.

		Buyers' price negotiatiability
Timing of price negotiation	Launching of new LNG project	Good
	Price review	Marginal
	Short-term/spot trading	Marginal

		Buyer's bargaining power
Market	Stringent: seller's market	None
	Easing: buyer's market	Substantive
Diversification	Energy sources	Substantive (only applicable for power companies)
	Suppliers	Conditional (only enforceable where multiple projects are running in parallel)
	Price formula	Effective for acceptance of new price formula (No guarantee to lower the price)

			Buyer's bargaining power
Purchase volume	Quantities	Small quantities	Marginal
		Large quantities	Substantive, with contrasting opinion for volume: – Possibe volume discount, and – Too large quantities may work
		Necessary quantity to launch new LNG project	Substantive
	Joint Purchase	All-Japan' procurement	Unlikely to be effective
		Alliance with partners who have a mutually complementary relationship	Substantive, regardless of nationalities.
	–	Likely to be no relationship between purchase volume and barganing power	
Upstream business		Small share	Margianl
		Price discount for project owner	Unlikely to be available
		Acquisition of project cost information	Effective, but only indirectly
		Promoting development of LNG projects	Effective, but only indirectly

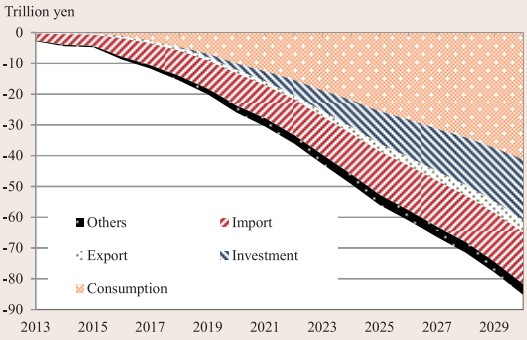


Fig. 1: Accumulated GDP loss in a "No-restart" case

In a "No-Restart" case, GDP will decrease 6 trillion yen in 2030 compared to the reference case and will reach 672 trillion yen. Accumulated loss of GDP amounts to 86 trillion yen beyond 2030.

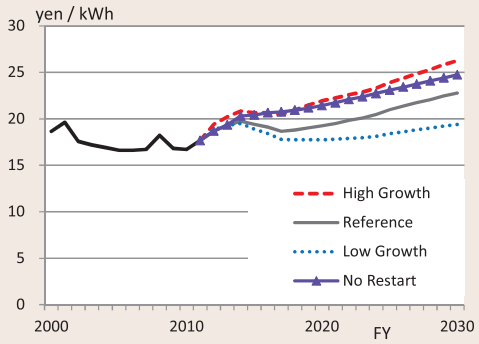


Fig. 2: Transition of electricity price

In a "No-Restart" case, nuclear power is assumed to be replaced with thermal power one by one alternating between LNG and coal. Our simulation does not include the effects of factors such as carbon constraints, location constraints and decommissioning costs. In our reference case, we assume that nuclear power stations will restart sequentially up until 2017, decreasing gradually along with the closure of old plants. Correspondingly, the impact on electricity price decreases gradually (the maximum difference is 2.3 yen per kWh, 11.5%) in a "No-Restart" case.

Basic Technology Subjects

System Engineering Research Laboratory

Brief Overview

The System Engineering Research Laboratory (SERL) conducts research on planning, operation, control, and analysis methods for electric power transmission, distribution systems, and information and communication systems, in order to facilitate the secure supply of electricity generated by large-scale and distributed power sources. The laboratory also pursues research on development, testing, and assessment of customer service technologies to achieve more efficient use of electricity.

Achievements by Research Theme

Electric Power Systems

Fundamental techniques of transmission system analysis and evaluations, control and protection for economic and stable operation of the system are developed. Also, using these fundamental techniques, solutions for recent technical issues surrounding the increase in renewable energy introduction, wide-area interconnection and so on are developed.

- The aging of transmission equipment is becoming a crucial issue, and adequate maintenance/replacement schemes (asset management) are required. Maintenance/replacement planning is an important part of this scheme. Currently, maintenance/replacement plans are developed separately from system upgrade plans. Therefore, we developed a program which modifies initial maintenance/replacement plans to harmonize them with system upgrade plans. This program contributes to developing more efficient maintenance/replacement plans. (R12009)
- There is a possibility of harmonic instability occurring in the case of parallel operation of an existing line commutated converter and newly-built voltage source converter when additional frequency converter is constructed. We analyzed the harmonic instability, and revealed the cause and occurrence condition of harmonic instability through transient simulation by XTAP (eXpandable Transient Analysis Program) (R12010).
- A fault clearing method using DC circuit breakers has been proposed for multi-terminal high voltage DC transmission systems which will be applied to the power transmission of long-distance wind power resources (R12007).

Customer Systems

Elemental techniques and tools to support promotion of customer energy saving are developed. Elemental techniques to support effective operation and maintenance for photovoltaic power generation of mega solar system are also developed.

- By comparing the seasonal energy consumptions of marketed air conditioners with the estimate value obtained from the same model, we verified that the developed heat source characteristic model, used to estimate power consumption of household air conditioners, which is an elemental technique to support promotion of energy saving, could be applied to various commercially sold air conditioner models. (R12002)
- Problems of conventional standard, such as the number of *tatami* mats which is a basis for choosing household air conditioners, were extracted. To promote energy saving by avoiding such problems, we devised a new tool to assist selection of appropriate air conditioners taking account of various lifestyles (Fig. 1) (R12008).
- For the development of a convenient on-site failure detection technology of photovoltaic (PV) modules using power conditioning systems (PCS), a method to detect PV modules failure by measuring change of current-voltage characteristics (I-V characteristics) which can be executed by PCS, was invented. It was confirmed by the results of a simulation and experiments that the proposed method could possibly be applied to detect connection failure and disconnection fault including mega solar systems. (R12017)

Communications Systems

In order to secure highly reliable communications networks for power utilities required for the operation and control of power systems, we develop disaster tolerance improvement technologies of communication systems, communication system construction technologies for restoration assistance at damaged power systems and security technologies for SCADA systems.

- In order to enhance the lightning protection ability of microwave wireless communication equipment used as important communication network for power utilities, a configuration which reduces the effects of lightning surges by applying an optical fiber transmission technique to a waveguide of wireless communication equipment was proposed. We have estimated the effect of added noise in optical transmission and expect to achieve the required communication quality (Fig. 2). (R12006)

In order to improve disaster tolerance of optical networks connecting distribution substations and wireless access points for smart meters, we have proposed a novel network system using optical switches for transmission lines altering at trunk lines of the passive optical network and experimentally demonstrated communication recovery behavior after disconnecting failures. In addition, we estimated the effects of optical transmission loss increased by the optical switches and circumventing transmission paths and believe that the proposed system could be applied in standard residential areas. (R12019)

Mathematical Informatics

To achieve accurate diagnosis in the maintenance and inspection of electric power equipment, we develop diagnosis methods based on high performance machine learning and image processing techniques. We also develop optimization methods for complex large-scale systems.

To efficiently support the maintenance and inspection of power equipment, we propose a new classification procedure which can detect abnormal signs and classify them into groups using similarity between the values of engaged sensors and the values of abnormal signs' sensors. When this procedure was applied for one year to the running data of a hydroelectric power plant, the proposed classification procedure detected 29 abnormal signs, appropriately classifying 25 of these into mechanical abnormal signs and 4 into composite abnormal signs.

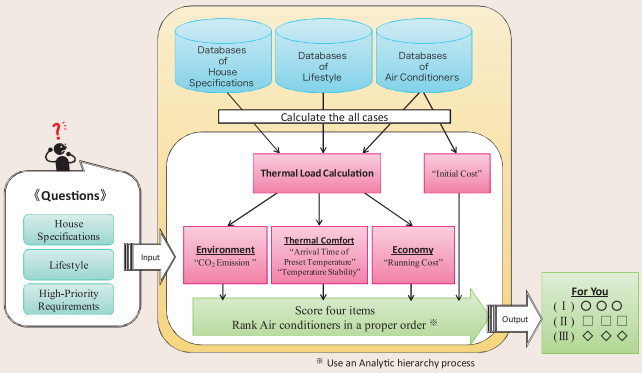


Fig. 1: A tool assisting the selection of appropriate air conditioners

After consumers enter information about their way of life, that is, the specifications of their house, their lifestyle (how frequently and for how long they use their air conditioner), and the values they allocate to consumer preferences (the environment, the thermal comfort, and the economy)—the air conditioners available for purchase on the market are automatically ranked on the basis of a database of information previously recorded on a tablet or other device. This quickly shows consumers the model that is the best fit for them. Through this method, consumers are able to rationally and easily make their choice from the various models.

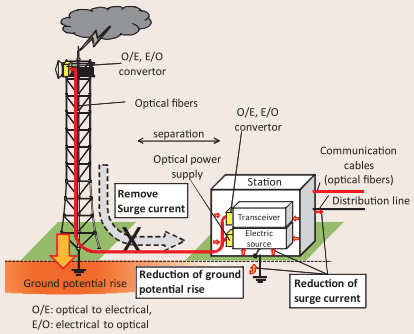


Fig. 2: A configuration of microwave wireless communication equipment using optical fiber for lightning protection

Electrical insulation between an antenna placed on a tower and wireless communication equipment in a room is provided by replacing the waveguide with optical fibers. An O/E (optical to electrical) convertor installed on the tower side is driven by optical power supply and electrical circuits are minimized by using a radio-on-fiber technique in order to enhance lightning protection ability by potential equalization.

Basic Technology Subjects

Nuclear Technology Research Laboratory

Brief Overview

The Nuclear Technology Research Laboratory aims at positively contributing to the solving/alleviation of energy and global environmental problems by developing nuclear technologies, including base technologies to support the safety and stable operation of LWRs as well as recovery from the accident at the Fukushima Daiichi nuclear power plant, so that the use of nuclear energy is accepted by society in a positive manner.

Achievements by Research Theme

Reactor Systems Safety Technology

To enhance safety and support stable operation of light water reactors, the reliability improvement of technologies related to the nuclear reactor system safety, such as, accident prevention, mitigation, emergency management, and preservation for high reliable operation have become important based on the experience of the Fukushima Daiichi nuclear plant accident.We aim to construct those fundamental technologies in connection with the field of thermal-hydraulics and risk assessment.

- We have been sophisticating TRACE code which was developed by the Nuclear Regulatory Commission (NRC) and has been used for safety regulations in the USA as a part of collaborative research with NRC. We suppressed numerical divergence and enhanced convergence of pressure at a liquid phase interface by implementing the liquid compressibility in the numerical solver.
- We have developed a new sensor called a "sub-channel void sensor" to acquire a cross-sectional distribution of two-phase flow in a fuel rod bundle. Based on experimental data, we validated the prediction error of the existing models to sophisticate the thermal-hydraulic analysis code for nuclear reactors.
- Common cause failure (CCF) analysis has an essential role in probabilistic risk assessment (PRA) for nuclear power plants (NPPs). Malfunction records of electrical and instrumentation devices in Japanese NPPs were investigated to find the CCFs and estimate the CCF parameters, which represent the existence ratio of CCFs to the whole failures, for use in PRA. The CCF analysis for the mechanical devices was already carried out last fiscal year. (L12004)
- For an evaluation of vibration fatigue of piping and components due to acoustic fluctuations caused at piping branches in wet steam conditions of an actual plant, wet steam experiments were conducted to clarify the effects of the steam wetness on fluctuations, and it was discovered that the amplitude of fluctuations decreased in proportion to steam wetness.

Nuclear Fuel and Reactor Core

Nuclear fuel and the reactor core are the heart of a nuclear power plant. In order to contribute to the enhancement of their safety, CRIEPI has been promoting the clarification of degradation mechanism of fuel cladding tube, the understanding of fuel performance under accident conditions, and the sophistication of reactor core analysis technology. The assessment of molten fuel characteristics and the development of subcriticality measurement technology are also being pursued for contributing to decommissioning of Fukushima Daiichi nuclear power plants.

- In order to confirm the integrity of fuel cladding when seawater is supplied to a spent fuel pool for emergency cooling, cladding tube specimens were immersed in artificial seawater. The test results indicated that no remarkable corrosion occurred in the specimens even in extreme seawater temperature of 80 to 85℃ and three times higher seawater ingredient concentration than natural seawater. This resistance to corrosion was due to a precipitation layer formed from seawater ingredients on the specimen surface. (L12001)
- Neutron was irradiated to a subcritical assembly simulating a mixture of nuclear fuel and steel, which forms as a result of a core meltdown, and the energy spectrum of gamma-ray emitted from the assembly was measured. The numerical analysis based on the gamma-ray spectrum measurement result was able to determine the ratio of nuclear fuel to steel in the mixture. This indicates that the subcriticality measurement technology under development by CRIEPI is applicable to molten fuel.

Nuclear Fuel Cycle

The necessary technical developments for the early stages of commercial operation of the Rokkasho reprocessing plant were carried out. Basic data for stable operation and safety improvement was also obtained. To maintain our world-top

ranking for the developmental level of our FBR fuel cycle technologies we engage in collaborative studies with other institutes in Japan and/or foreign countries. By applying these technologies, prevention technologies for radioactive contamination in a severe accident were also developed.

- The so called "Yellow phase"*1, which sometimes forms in the glass metler was examined comprehensively with attention to the basic physical property, dissolution behavior in the final repository and the diffusion and dissolution behavior into the glass. The obtained results are utilized in the developing activities for next generation glass melters.
- In order to evaluate the applicability of pyro process technologies, which were originally developed for FBR metal fuel cycles, to the treatment technologies for defected fuel generated in core meltdowns, the electroreduction tests using the simulated defected fuel containing U and Pu or the defected fuel generated in the TMI (Three Mile Island Nuclear Power Plant) accident were carried out. It was revealed that the uranium in the defected fuel can be converted to metal*2. Based on the obtained knowledge, we will continue to research the application of pyro technology to defected oxidized fuels.
- CRIEPI continued the operation support for the contaminated-water treatment system in Fukushima Daiichi Nuclear Power Plant and proposed effective operation conditions for cases in which salt concentration is reduced in the contaminated water.

Human Factors Research

In order to contribute to building an organization that exhibits good performance without any human error during both normal operation and emergencies, we will develop measures toward preventing human error and fostering a safety culture by bringing out the features of individuals, teams, and organizations.

- We developed a questionnaire instrument to assess the idealized image of effective power plant operator teams in three different levels of emergencies. This instrument makes it possible to share the ideal images of good team work, necessary for efficient training, among the concerned people (L12005).
- We found that extending the diversity of subjects' knowledge regarding causal factors (ex. unclear operation manual) through a 10-minute lecture on the factors has a beneficial effect on improving one's ability to detect unsafe acts. This suggests that a simple lecture on causal factors before the start of a shift improves workers' (especially inexperienced ones) ability to detect unsafe acts (L12006).

*1 Salt phase containing a high amount of Mo or S, which is separate to the glass phase.
*2 In collaboration with Japan Aeronautical Engineer's Association (JAEA) or Institute for Transuranium Elements (ITU,EC)

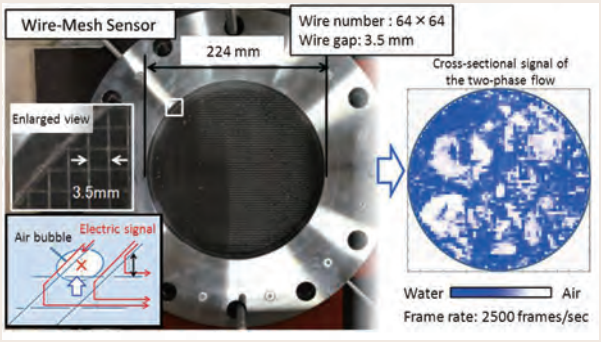


Fig. 1: Schematics of the Wire-Mesh Sensor (WMS)

WMS consists of a pair of parallel wire layers located at the cross-section of a pipe. The WMS measures the cross-sectional void distributions based on local conductivity. CRIEPI's WMS is 224 mm in internal diameter, consists of 64 × 64 parallel wires (3200 measuring points) and can measure the two-phase flow at high speed (2500 fps). Moreover, two sets of WMSs are installed to measure bubble velocity. Slope depends on the aging temperature.

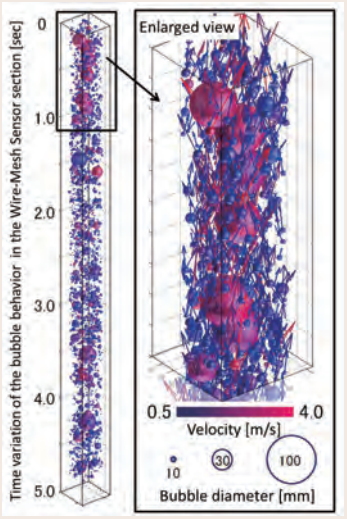


Fig. 2: Visualization of bubble behavior

Three-dimensional bubble velocity is determined by the tracing bubble. The circle size indicates bubble size and the arrow (color) indicates bubble behavior (velocity).

Basic Technology Subjects

Civil Engineering Research Laboratory

Brief Overview

The Civil Engineering Research Laboratory extensively promotes studies regarding geology and geotechnical engineering, earthquake engineering, structural engineering, and fluid dynamics, which are essential for maintenance work and natural disaster mitigation at electric power civil engineering facilities, as well as for back-end management in nuclear fuel cycle and underground energy utilization technologies.

Achievements by Research Theme

Geosphere Science

To solve issues associated with the siting and construction of electric power facilities and maintenance and asset management for aging facilities, we quantify evaluation methods for earthquake faults, estimation methods for explosive magnitude of volcanic eruptions, assessment methods for the stability of underground facilities, and methodology for groundwater solute transport modeling.

- To understand the seismic activity of faults, we have investigated surface fault ruptures and slip distributions caused by the normal-fault earthquake which was thought to be triggered by the 2011 off the Pacific coast of Tohoku Earthquake. Results showed that maximum displacement was observed the closer the distance to the epicenter and frequency distributions of slip for this event were consistent with those of other normal-fault earthquakes that have occurred in the past
- To evaluate fault activities and eruption histories, we expanded the applicability of radiometric dating methods such as radiocarbon, K-Ar, and U-Pb. Especially, by using LA-ICP-MS U-Pb method, we found that latest intrusion age of exposed granite in the Northern Japan Alps is around 800,000 years ago and showed that this method is applicable for Quaternary dating.

Earthquake Engineering

We aim to establish proper countermeasures to control risks on natural disasters, mainly earthquakes, for electric power facilities and equipment. We also develop low-cost solutions to maintain electric power facilities.

- We clarified that the damage of a transformer bushing in a substation during the 2011 off the Pacific coast of Tohoku Earthquake was caused by strong ground motion exceeding the current design level. We also found that the acceleration response spectrum enveloping over 90% of the observed records corresponded to two times the design level (N12016).
- The early restoration of the power-supply system after a great earthquake depends on not only electricity in isolation but also critical infrastructures such as communications, transportation, etc.,. We reviewed the current research status of critical infrastructure interdependency analysis in order to contribute to the optimal strategies for early restoration of the power-supply system. We found that the causes of critical infrastructure interaction are classified into two types, namely physical proximity and functional dependency. The review also showed that four modeling methods, such as the Agent-based Model, are the typical methods for analyzing interdependency, and the selection of a method appropriate for the intended use is necessary (N12017).

Structural Engineering

To secure the safety and reliability of steel and concrete structures as well as extend their lifespans, we develop structural performance evaluation methods considering natural hazard actions such as earthquakes, wind, heavy snow, along with aged deterioration caused by environmental actions such as chloride-induced deterioration, frost damage and temperature changes.

- By conducting cyclic loading tests using full-scale specimens of a reinforced concrete (RC) underground structure, we evaluated the effects of cracking damage caused by earthquakes and the following reinforcing steel corrosion on load carrying capacity of an RC box-culvert (Fig. 1). We also developed a consideration method of cracking damages for evaluating the residual load carrying capacity. These results can be applied to the soundness evaluation of the RC underground structures at thermal and nuclear power plants that experience earthquakes. (N12013)
- To enable the evaluation of effective diffusion coefficient of chloride ion more precisely in a short time, one of the most important physical properties used for prediction of chloride induced degradation in RC structures, we developed a quick evaluation method which can estimate the coefficient in approximately 1/3 of the time as conventional measurements, by combining the standard test method (electrical migration method) authorized by the Japan Society of Civil Engineers and a numerical analysis model. (N12018)

Fluid Dynamics

In order to evaluate the impact of volcanic eruption and fires on the safety of nuclear power plants and also to improve construction, operation, maintenance, and natural disaster mitigation technologies for hydro, solar and wind power plants, we strive to develop basic evaluation technologies of hydraulic and atmospheric fluid flows relevant to such facilities.

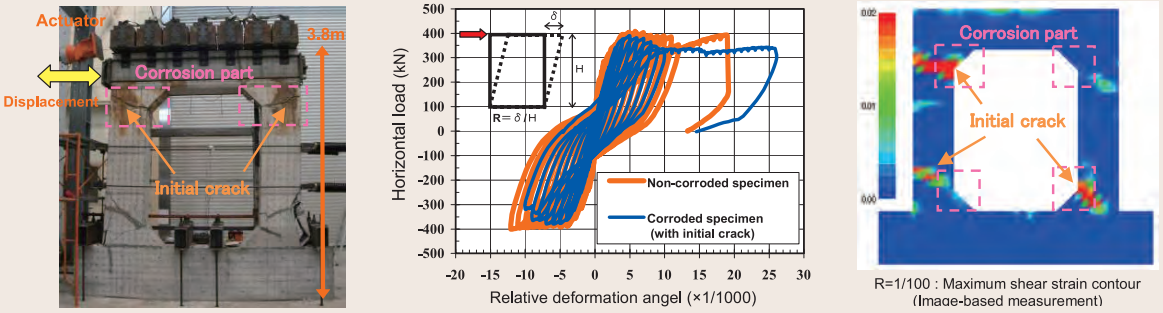
- We have developed a method to evaluate the reliability of solar radiation forecasts using weekly ensemble forecasts provided by the Japan Meteorological Agency so that we can effectively utilize a one-day forecast result produced by our weather model for prediction of solar power generation. The applicability was examined by checking the degree of correlation between the reliability indicator and the prediction error of our weather model. Moreover, a method has been developed using geostationary meteorological satellite data in order to forecast solar radiation at ground level in several hours. (V12015)
- A hydraulic experiment was conducted to acquire data of temporal evolution of a scour hole upstream from a dam gate using prolonged automatic configuration measurement. The experimental results are successfully summarized in a dimensionless manner to draw a correlational formula between scour volume and relevant hydraulic parameters. The empirical formula allows us to predict a temporal evolution scour in actual dams for hydro-electric power stations. (N12002)

Underground Energy Utilization Technologies

We aim to develop exploration and evaluation technologies for utilizing underground space and developing underground energy such as CO_2 geological storage, large scale electric power storage, geothermal power generation, and so on.

- It is necessary to prepare information for discussing the introduction of CCSR* policy to construct new coal power plants in the future in Japan. We collected information of present oversea CCSR regulation and policy. Furthermore, we illustrated results of CCSR assessment conducted by an electric power company as part of consent application for constructing new power stations in the United Kingdom. (V12013)
- Through collaborative field experiments in which CO_2 was emitted under the sea floor in the United Kingdom, we predicted underground CO_2 behavior and CO_2 dispersion in the sea by numerical simulation. We also conducted monitoring of underground CO_2 distribution using electric methods and measuring CO_2 concentration in the seawater using an autonomous underwater vehicle. We obtained important practical data for considering environmental impact of CO_2 migration from under the sea floor to the sea.

* CCSR is the abbreviation of "Carbon-dioxide Capture and Storage Ready". This means to secure lands and so on for preparing addition of CCS apparatuses in the future.



(a) Outline of loading test (ultimate state) (b) Example of experimental results (case of initial crack corresponding to yielding of steels)

Fig. 1: Full-scale loading tests for RC box-culvert

Despite the degree of initial cracking damage, the maximum strength of the RC box-culvert specimens with corroded reinforcing steels slightly decreased, although the average corrosion amount of the cross section of reinforcing steels decreased up to approximately 10%. This was because sectional forces were redistributed after cracking. However, in cases where the initial cracking damage levels corresponded to yielding of the reinforcing steels, such as an initial crack width of 0.4mm, the local damage became larger in the after maximum strength due to the corrosion of reinforcing steels. And, in these cases, the strength at a 1/100 relative deformation angle decreased to approximately 80% of when there is no corrosion.

Basic Technology Subjects

Environmental Science Research Laboratory

Brief Overview

The Environmental Science Research Laboratory has promoted basic research on atmospheric, river, coastal and marine environments as well as biology, chemistry, and biotechnology, for the construction and stable operation of electric power facilities, establishment of a low-carbon society, and reduction of various environmental risks associated with the electric power industry.

Achievements by Research Theme

Atmospheric and Marine Environment

The target of research in this field is to develop technologies for predicting and assessing atmospheric and marine environments in order to respond to problems such as air pollution associated with thermal and nuclear power plants and the marine dispersion of radioactive materials.

■The effect of building downwash[*1] was investigated by numerical simulation to help determine a reasonable stack height in thermal power plants. By clarifying the relationship between the stack height and the surface concentration of exhaust gas, an approximate equation that expresses the relationship between the maximum surface concentration and the stack height was proposed to easily estimate the stack height necessary to effectively disperse exhaust gas (V12003).

River and Coastal Environment

The target of research in this field is to develop technologies for investigating, predicting, and assessing hydrospheric environments in order to solve related environmental problems. These environments include aquatic environments, such as rivers and reservoirs, which are affected by hydraulic power plants, as well as environments near coastal power plants, such as thermal and nuclear power plants.

■A model that considers the habitat environment of benthic organisms such as aquatic insects in rivers (physical habitat simulation model - PHABSIM) was incorporated into a tool for predicting and assessing river environments that can be used in updating water usage rights and supporting sediment throwing in hydropower dams. A method of efficiently monitoring the change in river environments using biological indicators was also developed.

■We developed a method of estimating the water temperature and velocity of submerged thermal discharges on the sea surface for various discharge conditions with the aim of rapidly assessing the dispersion area of discharges from thermal and nuclear power plants. Using this method, we developed a simple simulation technique to easily estimate the dispersion of thermal discharges on a PC and verified its applicability (Fig. 1) (V12018).

Biological Environment

The target of research in this field is to develop methods to prevent electrical accidents caused by biofouling organisms, birds, and animals as well as to prevent forest soil erosion causing soil runoff to rivers and reservoirs in order to reduce the labor required to maintain power plants and resolve related environmental problems. The risk of electromagnetic fields on health is also analyzed.

■Barnacles and golden mussels attach themselves to water intake channels in maritime power plants and the water pipes of hydroelectric dams, respectively, and inhibit the flow of water. We clarified the effects of chlorine and ozone on preventing such attachment through examinations under various water quality conditions and obtained the basic knowledge necessary to develop practical preventive techniques.

■We exposed rats to intermediate frequency magnetic fields at the intensity higher than international exposure guidelines for general public. After exposure, no significant changes were observed in body weight, blood chemistry, and histopathology of the organs. The results suggested that intermediate-frequency magnetic fields generated from home appliances have no adverse effects on human health (V12001).

Biotechnology

The target of research in this field is to develop technologies that use microorganisms to reduce and recycle waste and to treat drainage water. Technologies to create an energy-efficient environment for plant-growing factories and to utilize renewable energy are also developed.

■A numerical calculation model for assessing the thermal and air environment within plant-growing

factories was developed as a means of saving energy in such factories using heat pumps. The applicability of the model to small greenhouses was verified (V12004).

- The fuel characteristics of plant oil produced from Jatropha used in diesel engines for power generation were assessed with the aim of utilizing biomass as fuel for power generation. The fuel characteristics comparable to those of light oil were obtained by reducing the viscosity and other factors of plant oil (V12014).
- We improved the pretreatment method for samples to be tested using microbiosensors that detect mercury in water discharged from coal-fired power plants. This increases the likelihood of creating a simple method of monitoring mercury concentration below the maximum allowable level set for discharged water and controlled landfill sites (V12010).

Environmental Chemistry

The target of research in this field is to develop effective technologies for utilizing byproducts, such as coal ash and desulfurization gypsum, generated at power plants as well as low-cost technologies for managing and treating trace elements in effluents discharged from power plants in order to support the high-load and stable operation of coal-fired power plants.

- A pretreatment method for rapidly and ultrasonically eluting mercury in coal ash was established to support its management. This has led to the realization of quantitative analysis (0.01-1.0 mg/kg) by inductively coupled plasma optical emission spectrometry (ICP-OES), which has been adopted by many power plants (V12002).
- A technique was developed for stabilizing heavy metals in industrial waste such as fly ash under alkali conditions. This uses our method developed for synthesizing hydroxyapatite from desulfurization gypsum as a raw material*2.

*1 A phenomenon in which the surface concentration of gases increases when such gases enter the vortices and downflow generated behind buildings.
*2 Joint research with Kurita Water Industries Ltd.

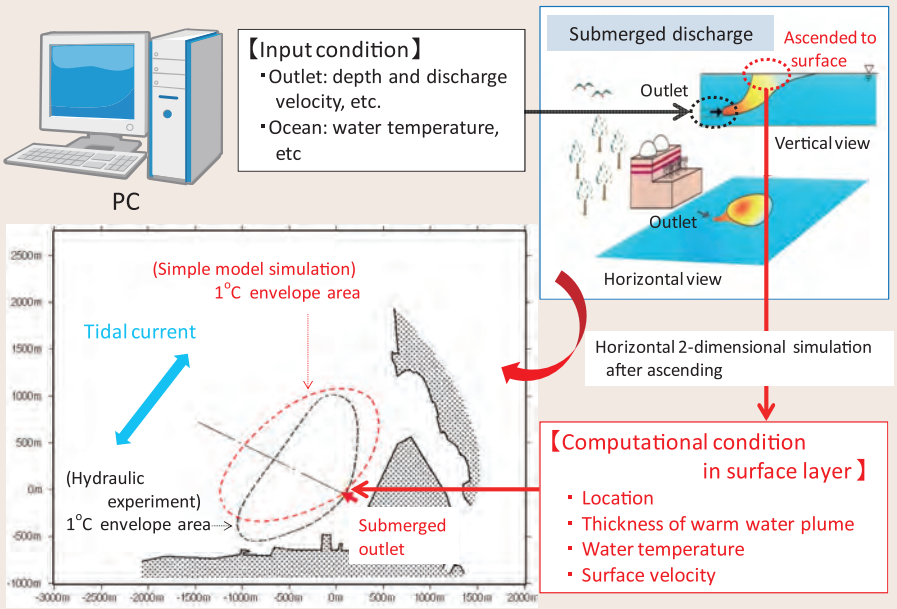


Fig. 1: Simple simulation method developed for submerged discharge and comparison with experimental results

The dispersion of submerged thermal discharge is complicated. The results of a hydraulic model experiment and a three-dimensional model are used to estimate the area of water temperature increase resulting from the dispersion of submerged thermal discharges. In the developed method, the location, velocity and water temperature of a submerged thermal discharge ascended to the sea surface are estimated for different discharge and hydrographic conditions to easily predict the dispersion area of the thermal discharge at surface layer. The 1℃ temperature increase area observed in the simulation was practically consistent with that of the hydraulic experiment with a tidal current in the sea (left figure). The developed method is more cost-effective than hydraulic experiments and three-dimensional simulations and can greatly reduce the calculation time, making it effective for examining marine strategies at the planning stage.

Basic Technology Subjects

Electric Power Engineering Research Laboratory

Brief Overview

The Electric Power Engineering Research Laboratory is engaged in the advancement of fundamental technologies, including electrical insulation, lightning protection, high-voltage and high-current technologies for power transmission and distribution equipment. It is also developing next-generation power equipment and new electric power technologies such as laser, arc plasma and power electronics application.

Achievements by Research Theme

High-voltage and Insulation

We aim to clarify the deterioration mechanism of solid electrical insulation materials used in aged electrical equipment, advance external insulating technology for transmission lines, improve the accuracy of high voltage measurements and evaluate new insulation materials for next-generation power transmission and distribution equipment.

- The residual charge method with pulse voltages was improved as a diagnosis method for water tree degraded XLPE cables and applied to removed 6.6 kV XLPE cables. As a result, signals relating to water tree degradation were successfully measured and AC breakdown voltages of the removed cables could be estimated from the amplitude and duration of the signals. Therefore, this method is applicable to 6.6 kV XLPE cables in the field as a cable diagnosis method*1.

Lightning and Electromagnetic Environment

We aim to establish reasonable measures to deal with lightning damage and develop insulation coordination technology for power systems in an information-communications technology (ICT) society, as well as establish technology for electromagnetic compatibility (EMC) in power systems and consumer equipment.

- In order to locate the position of insulation deterioration points on electric power equipment, a system for locating the source of electromagnetic noise caused by spark discharge generated on insulation deterioration points was developed. The developed system is applicable for multipath environments, and can locate the position of the source with high accuracy (Fig. 1) (H12004).
- The concurrent flashover process of two parallel arcing horns*2 was observed by a highspeed camera for the purpose of clarifying multiphase faults on transmission lines caused by lightning. Based on experimental result, a relational expression was derived to estimate the concurrent flashover rate. Moreover, this result leads to improvement of the lightning outage rates program, "LORP" (H12012).
- A series of numerical calculation codes was developed to investigate compliance testing with existing guidelines limiting human exposure to several types of electromagnetic fields. These codes include: (1) a postured voxel-based human body model which simulates several exposure conditions of workers in a variety of postures, (2) a calculation code for internal electric fields induced by outer electric fields, and (3) a calculation code for SAR (specific absorption rate) caused by radio frequency electromagnetic fields (H12006).

Applied High Energy Physics

We aim to develop simulation methods of pressure rising and propagation characteristics to complement the internal arc testing of electric power equipment, as well as innovative measurement technologies using laser and optical technologies and to work on their application toward the diagnosis of power delivery apparatuses. We also develop plasma melting technology to reduce the volume of radioactive waste for disposal.

- When a fault arc occurs in electric power installations, the internal pressure rises steeply due to gas heating, which may cause severe damage to the installations and their surroundings. Reduction of the internal pressure rise is required to minimize damage. We clarified that it is brought about by the intentional melting and vaporization of copper or iron metal, which can be installed by a fault arc as a partition or similar inside the installation.
- The thermally grown oxide layer, which forms under the topcoat of thermal barrier coating (TBC) of gas turbine blades during operation, is one cause of topcoat delamination. A simple nondestructive inspection method to detect the thermally grown oxide layer was developed. This method is capable of rapid detection, and will enable effective maintenance of turbine blades by combination with precise delamination detection methods (H12011).
- In order to expand the application of plasma melting to the low radioactive solid wastes, the applicability of plasma melting method to the high melting points of wastes such as soil is clarified. We elucidate clarify the appropriate kind types and the additive amounts of flux to melt soil (H12008).

Electric Power Application

We aim to develop analysis methods for electric power quality and technologies for the design and management of reasonable electric power systems connected by power electric equipment by developing cooperating technologies with customer side equipment for improving electric power quality.

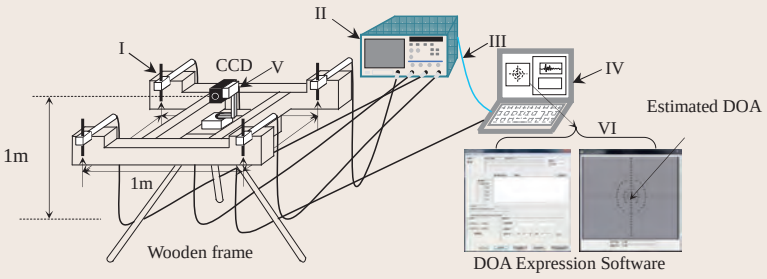
■We increased calculation speed of the Electromagnetic Transient Analysis Program for Power Systems (XTAP), by improving algorithms, and added a calculation menu of frequency response characteristics. Also, we made basic simulation models for switching transient overvoltage caused by switching operation of circuit breakers, which are very important in terms of the insulation design of power transmission lines (H12005).

High Current Technology

To estimate the performance of electric equipment when short-circuit faults occur, we aim to improve short-circuit test techniques and establish measuring techniques for frequency currents.

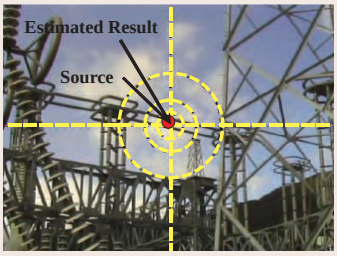
■The melting time of metal wires used for arc ignition in high power arc tests for investigating the short-circuit performance of electric equipment was calculated. The results showed that thin metal wires should be used to melt in a short time when transformers with cutout fuses are tested.

*1 Cooperative research with Chubu Electric Power Co., Inc.
*2 Arcing horns are attached to both ends of insulator strings to suppress the overvoltage across the insulator strings.
*3 DOA: Direction of Arrival.

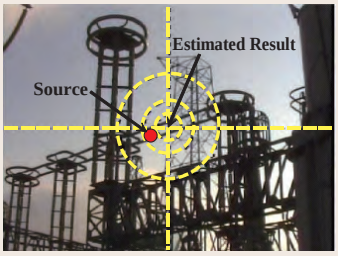


Ⅰ. Receive waveforms on four dipole antennas (Center frequency: 500MHz)
Ⅱ. Express the waveforms on oscilloscope (DC~12GHz, sampling rate 50GS/s)
Ⅲ. Load waveforms on PC through LAN cable
Ⅳ. Estimate DOA*3 by using the developed program
Ⅴ. Aim the camera automatically by the program command to the estimated DOA
Ⅵ. Display and record the picture

(a) Configuration of the developed locating system



(b) Example of location result (less interference on electromagnetic propagation path)



(c) Example of location result (much interference on electromagnetic propagation path)

Fig. 1: Configuration of the locating system and location results

(a) shows the configuration of the developed locating system. The system is composed of four dipole antennas, oscilloscope, PC and a CCD camera. The signals received by the antennas are sampled and processed by oscilloscope and PC. The position of the source can be located and displayed by the developed program and the camera. (b) and (c) shows the examples of location results. The red point is the position of the source, and the center of the circular broken line is the located position. It is shown that the position of source can be located with high accuracy whether less or much interference on the electromagnetic propagation.

Basic Technology Subjects

Energy Engineering Research Laboratory

Brief Overview

The Energy Engineering Research Laboratory is aiming to achieve energy security as well as construct power and energy supply and demand systems, through R&D of clean and high efficiency thermal power generation technologies and advanced heat utilization systems.

Achievements by Research Theme

High Efficiency Power Generation

To decrease maintenance cost, and improve the operability and efficiency of thermal power plants, rational operation and maintenance technologies and the utilization technology of new liquid fuels for gas turbines and the boilers are under development.

- Nondestructive testing methods for thinning and sintering were established concerning damage and degradation (thinning, sintering and delamination) of thermal barrier coatings of gas turbine blades. Furthermore, a simple and nondestructive testing method for delamination was developed by combining laser heating with temperature measurement using infrared cameras (M12002).
- Miniature sample creep tests[*1] have been performed to accumulate reference data for the specimen-size dependency of creep strength. The samples tested were taken from actually disposed boiler tubes experiencing long-term services. Improvements of testing techniques are currently required to develop an appropriate damage assessment of thin-walled boiler tubes and gas turbine buckets with complex geometries.
- Evaluation methods were investigated for liquid fuel degradation during storage. Regarding bio-fuels, degradation mechanisms such as oxidation and physical –chemical properties for evaluation were clarified.

Advanced Fuel Utilization

For the diversification of energy resources and improvement of the environmental friendliness of coal-fired power plants, studies are underway concerning combustion enhancement of low grade coals, evaluation and control of spontaneous ignition of solid fuels, measurement methods for trace elements, and manufacturing of solidification material using fly ash.

- In a waste water treatment, the removal performance of selenium from the waste water of a flue gas desulfurization depends on the existing form of selenium. We developed a new speciation method (limit of quantification: 1 μg/L) which can analyze Se(0) and Se(-II) in addition to the common forms of Se(IV) and Se(VI).
- To expand fly ash utilization, solidification material made of fly ash(FA) and shell waste powders was produced and applied to shoreline maintenance. The product was clarified to have highly compressive strength (M12007).

Heat Pump and Thermal Storage

For developing high-efficiency heat pumps and expanding their application areas, we investigate and analyze the latest trends in heat pumps innovation and related standards, and improve elemental technology of heat exchangers.

- The current development trend regarding commercial air conditioners is to improve the efficiency at low load where the load factor is 50% or less. This can achieve energy savings by an average of more than 30% per year. However, the current standard can't reflect this efficiency improvement and must be revised.
- Regarding the proposed frost-free heat pump, the solid desiccant coated heat exchanger was prototyped. Its heat and mass transfer characteristics were investigated experimentally. It was discovered that the heat exchanger must be designed with consideration to the ratio of the heat transfer rate and mass (water) transfer rate.

Energy Conversion Engineering

Basic technologies that relate to the evaluation of thermal efficiency, fuel cells, and advanced material analysis, etc., are being developed to improve operability and thermal efficiency of thermal power plants and geothermal power plants.

Achievements by Research Theme

- In the development of a 40 MW AHAT*2 (Advanced Humid Air Turbine), CRIEPI contributed to the achievement of rated power by verifying the effect of air humidification quantitatively through the system analysis.
- An operating data analysis system for geothermal power plants was developed to evaluate the thermal efficiency of the system and the performance of individual equipment. This system was introduced in geothermal plants and used for performance analysis at periodic inspections and/or reconstruction.
- SOFCs (Solid Oxide Fuel cells) manufactured by five manufacturers were tested for an extended period of time*3. Dominant performance factors for SOFC degradation were revealed by performance factor analysis and a method to evaluate degradation performance was established.
- A high performance SOFC power generation system was proposed in which a half of SOFC module is operated at fixed power and the latter half follows the change of power output. A system analysis showed that the efficiency of the system varied from 51% to 54% (High Heating calorific Value of Natural Gas) depending on the power output (13,000-46,000kW) (M12004).

Innovative Numerical Simulation Technology

A comprehensive numerical simulation tool is being developed to solve issues in thermal power plants such as pulverized coal combustion boilers, coal gasifiers, and gas turbines.

- A numerical simulation was performed on a commercial pulverized coal combustion boiler using existing numerical models and was compared with the measured data. The result revealed that the development of physical and numerical models which had high scalability and accuracy were essential.
- A numerical model was developed to precisely predict temperature distribution on a gas turbine rotor blade by means of a large-eddy simulation (LES). It was found that the density ratio of the cooling flow to main flow and the film cooling hole's shape significantly affected the cooling efficiency.

*1 A testing method to evaluate degradation of highly damaged portions by sampling specimens smaller than a standard sample in size. Such samples taken from highly stressed portions in real components exposed to high temperature services.
*2 MITI subsidies project performed with Hitachi Ltd., Sumitomo Precision Products Co., Ltd. and CRIEPI.
*3 Commissioned research from New Energy and Industrial Technology Development Organization.

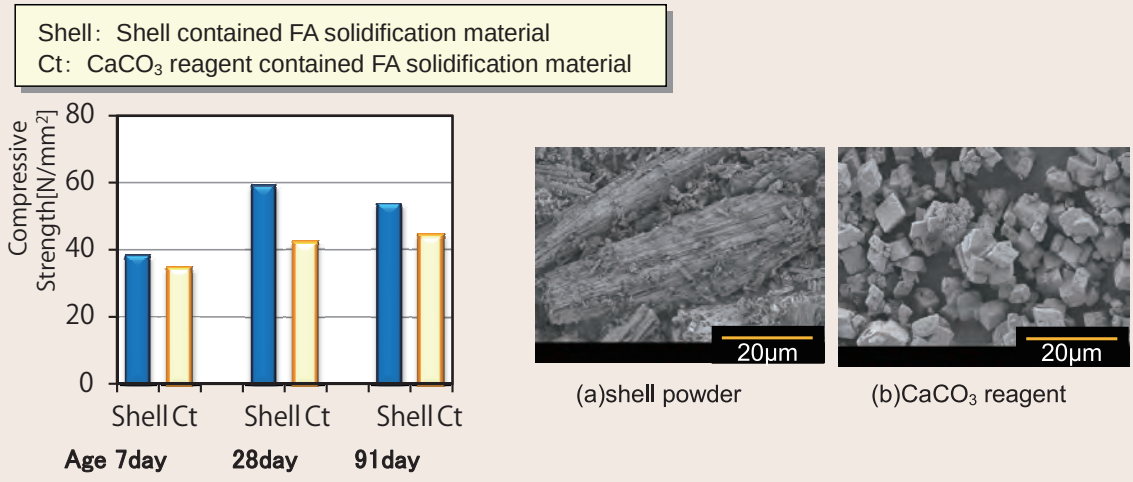


Fig. 1: Influence of shell powers on compressive strength of FA solidification material and SEM photographs of a shell powders and $CaCO_3$ reagent

The bar graph shows the compressive strengths of FA solidification materials with a shell powders and with $CaCO_3$ reagent. It was found that the addition of shell powders achieved higher compressive strength after the 28th in the material age. The SEM photographs shows that the shell powders have layered structures of calcium carbonate while the $CaCO_3$ reagent powders are in cubes. It is thought that the layered structure contributes to the improvement of the compressive strength of the solidification material.

Basic Technology Subjects

Materials Science Research Laboratory

Brief Overview

The aim of the Materials Science Research Laboratory is to contribute to reliable electric power supply and creation of a low-carbon society through fundamental materials researches for field applications to electric power plants, renewable energy utilization, and new materials development for energy conservation.

Achievements by Research Theme

Materials for Nuclear Power Plants

In order to decrease radiation exposure and maintain component integrity, we investigate water chemistry and environmental effects on corrosion in nuclear reactor components.

- Fuel crud deposition was investigated under a simulated water environment of domestic PWR core regions with no radiation exposure. The results suggested that the control of dissolved hydrogen concentration for the mitigation of primary water stress corrosion cracking can be effectively utilized with the zinc injection for dose rate reduction.
- The impact of seawater leakage on crevice corrosion initiation and propagation was evaluated through experiments using the stainless steels of condenser systems. We have succeeded in determining the threshold chloride concentration beyond which crevice corrosion occurs in stainless steels (Q12001).

Structural Materials

We will contribute to the reliable and stable operation of thermal and nuclear power plants through research activities such as fundamental data accumulation of high-temperature materials strength and corrosion behavior, development of lifetime evaluation methods for aged structural components and the development of non-destructive inspection technologies.

- Alloy740H, which has the highest creep strength among various Ni-based super alloys candidates for an Advanced-Ultra Super Critical (A-USC) thermal power plant aiming to operate at 700℃, has demonstrated superiority over other alloys in terms of fatigue strength (Q12005).
- Grade 122 steel is a 12Cr ferritic steel which has had its performance improved by tungsten addition for use in current ultra-super critical power plants. We have developed new creep strain equations for Grade 122 to describe creep deformation behavior with sufficient accuracy (Fig. 1).
- The “Handbook on Water Treatment for Thermal Power Plants” was issued in 2012. This is a revision of the original version “Handbook on Water Treatment for Steam Power Plants” issued in 1985 by Japanese utilities and CRIEPI. State-of-the-art scientific understanding as well as the operation experiences of conventional steam power plants, advanced ultra-super critical plants and combined cycle plants are included in the revised handbook.

Materials for Energy Conversion and Storage

We will develop technologies to evaluate the field performance of photovoltaic (PV) systems to prepare for mass installation in the future. The application of ionic liquid and the fabrication of functional ceramic will also be studied for the effective use of renewable energy.

- A power simulation model applicable to crystalline Si PV modules oriented towards all azimuths was developed based on the correlation analysis between solar irradiance and PV performance. The accuracy of the model was demonstrated through comparison with the field data of 18 months measurement (Fig. 2). (Q12002)
- We investigated the performance of solvate ionic liquid as the electrolyte of lithium secondary batteries using a glyme – lithium salt equimolar complex electrolyte. The battery with a positive electrode of 3.5V-class $LiFePO_4$ showed a long charge/discharge cycle life of more than 500 cycles, while 400 cycle stable operation was also achieved with a sulfur positive electrode which is a candidate for the next-generation positive electrode.

Advanced Functional Materials

We will develop new functional materials such as superconductors and various organic semiconductors by utilizing our in-house techniques of growing high-quality crystals and controlling their basic physical properties.

■Transmission electron microscopy observation was performed on various kinds of iron-based superconducting thin films on several substrates. We found that chemical substitution between the substrate and the film induces lattice distortions leading to the change of superconducting properties.

■We have succeeded in fabricating a new type of organic light-emitting device using a very simple printing processsuitable for mass production. The device works at relatively low voltage achieving a light intensity of 1500 cd/m^2,which is three times higher than that of a conventional LCD TV.

Nondestructive Inspection

Our goal is to develop tailored ultrasonic testing (UT) methodologies, not only fornondestructive inspections of defects in power plant components, but also for evaluation of the degradation of material properties.

■A phased-array UT technique with a 5 MHz frequency was applied to defect detection in buried base bolts. A fatigue crack 2 mm in height was detected at a depth of 90 mm from the top of a bolt with a diameter of 24 mm, suggesting the applicability of the technique to the field inspection (Q12009).

Materials Science Research Fundamentals

We will promote fundamental research for predicting material properties and evaluating localized stress state by a combination of computer simulations and advanced materials analysis methods aiming at a breakthrough in materials research.

■First-principles molecular dynamics simulations have been performed to investigate the transportation mechanism of lithium ion between the positive electrode of $LiCoO_2$ and the electrolyte of ethylene carbonate (EC) in a lithium secondary battery. The results showed the binding between the oxygen of an EC molecule and the lithium and cobalt of $LiCoO_2$, suggesting the importance of oxygen in the transportation mechanism at the interface.

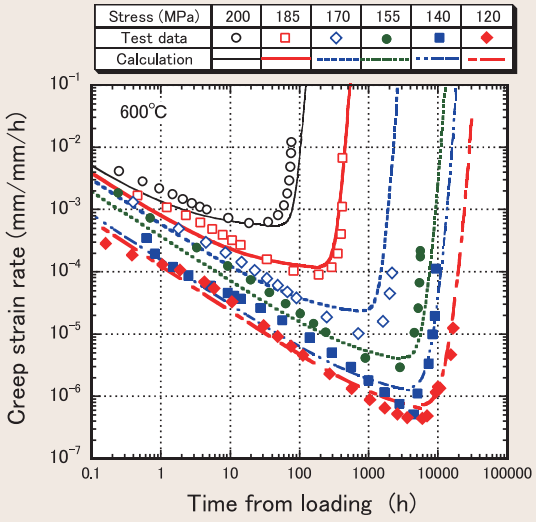


Fig. 1: Comparison of test data and calculation on the variation of creep strain rate

Creep strain equations incorporating the principal features of Grade 122 steel, such as an early transition to tertiary creep stage under high temperature/low stress conditions, have been developed in order to accurately describe the variation of creep strain rate throughout the steel's life under various loading conditions.

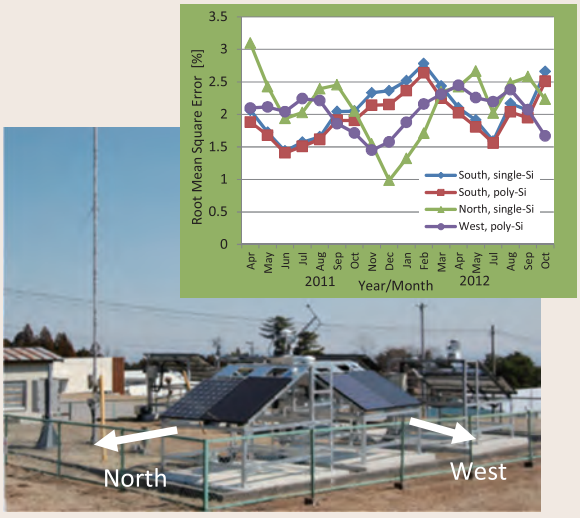


Fig. 2: Photovoltaic module test facility at Akagi Testing Center

The panels are oriented not only to the south, but also to the west and north, and tilted by 30°. Arrows indicate the azimuths. Power output can be predicted with an error of around 3% regardless of the panel azimuth.

3. Major New Research Facilities

Test Equipment for Examining the Multiple Interconnection Characteristics of PCS

Background

The amount of photovoltaic generation systems (PV) interconnecting with utility power systems is rapidly increasing due to the introduction of FIT. Problems associated with a high number of PVs are voltage fluctuation in power distribution systems, coordination of protection systems (preventing islanding, etc.) and simultaneous stops in the event of faults. The evaluation of PV systems by testing with a high number of PV systems is necessary in order to grasp these phenomena and study measures. As such, we installed equipment to simulate operation of PV arrays with high precision and to test many PCS of PV systems operating simultaneously in Akagi Testing Center. The equipment will be used effectively in order to extract problems caused in power systems in the future and to develop countermeasures.

Outline

The test equipment has 10 sets of high performance DC sources for simulating transitional phenomenon and 10 sets of DC sources for simulating steady phenomenon, making it capable of simulating a total of 20 PV systems. The equipment is equipped with 81kW low voltage source with sufficient capacity to test under the condition of reverse power flow and can simulate system turbulence such as instantaneous voltage drop and shifting voltage angle. Moreover, the equipment has RLC load systems equivalent to a low voltage source in capacity, grinder load used as low voltage motor load at attestation examination and impedance to simulate a low voltage distribution line. The equipment is connected to an existing experimental distribution system and BTB systems in order to evaluate interrelated influence between distributed generations (DG) interconnecting to middle voltage and/or low voltage systems and system turbulence caused by faults in transmission system. Using the above test equipment, the behavior of multiple PCS of PV in various conditions can be simulated, through which problems can be extracted and countermeasures can be studied.

Specifications

(1) DC Source : Capacity 4kW, Max Voltage 400V, Max Current 30A, Response Speed 100μs
(2) Low Voltage Source : Capacity 81kW (3P3W), 54kW (1P3W), Response Frequency 1kHz
(3) Load Equipment : R Load 63kW, L Load 30.6kvar, C Load 30.6kvar, Grinder Load 12 sets
(4) Low Voltage Line Impedance : 3 sets (R:30mΩ/set, L:45 μH/set)
(5) Measuring System : 1-cycle Interval root mean square value (Voltage, Current), Power (Active, Reactive), Frequency, Measuring instrument : Resolution 16-bit, 1MHz Sampling,
(6) Power Conditioning Subsystem : New type (Method of Frequency Feedback with Step Injection function) 14 sets, Conventional Type 20 sets or more
(7) Real PV Array : 5kW

[Installed location and date]

Akagi Testing Center / November, 2012

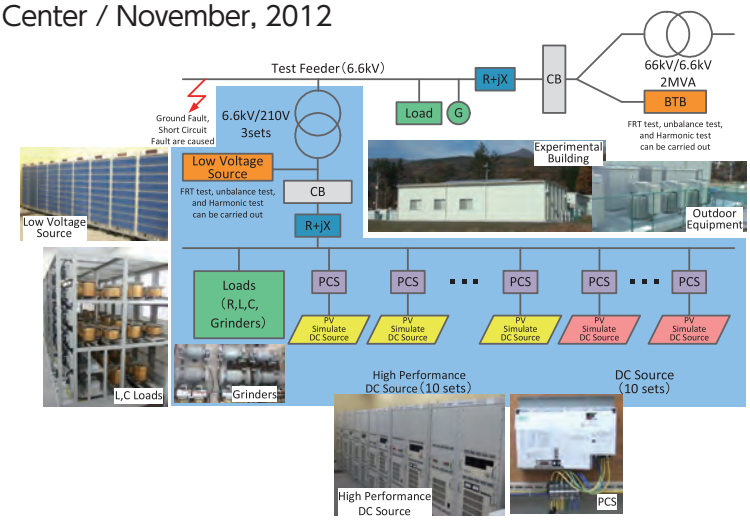


Fig. 1: Summary of Test Equipment for Interconnecting A Large Number of PCS

Long Length XLPE Cable Deterioration Testing System

Background

XLPE cable plays an important role in power transmission and distribution systems. Introduction of XLPE cable into the power grid began in the 1970's, and rapidly increased in the 1980's, therefore currently there is an increasing amount of highly aged XLPE cable which has been in operation for more than 30 years. In light of this situation, investigation on the deterioration of electrical insulation for such highly aged XLPE cable is an important challenge in supporting the establishment of the strategic replacement plans for the operating equipment, by high voltage tests with removed XLPE cable. This testing system aims to reveal the cause of deterioration of electrical insulation in the removed long length XLPE cable of 200-m length class, and adopts a pre-breakdown discharge detection technique.

Outline

This testing system consists of a 500 kV AC transformer to apply high voltage to the XLPE cable specimen enough to ignite the discharge in it. The pre-breakdown discharge detection technique is the most important technique in this testing system, in order to prevent the breakdown and burning out of the deterioration cause, by effectively detecting partial discharge, which is the precursor phenomenon of the breakdown, and locating it. Partial discharge free cable terminations are also adopted to increase certainty.

Specifications

High voltage source
- Maximum output voltage: 500 kV (no partial discharge), Maximum capacity: 1000 kVA
- Capacity of power source is reduced by resonance inductance.
- A high speed breaker is introduced to shut down the voltage application within 100 μs.

XLPE cable termination
- Two sets of water termination systems are adopted.
- Maximum voltage: 250 kV and 600 kV
- Forced circulation of ion-exchanged water is adopted for high voltage insulation and cooling.

Experimental hall
- Height: 11m, Capacity of overhead traveling crane: 1t, Turntable: 10 m in diameter

[Installed location and date]

Yokosuka area / March, 2013

* The water termination system sustains high voltage insulation by filling up the ion-exchanged water in it to prevent discharge noise in high voltage testing.

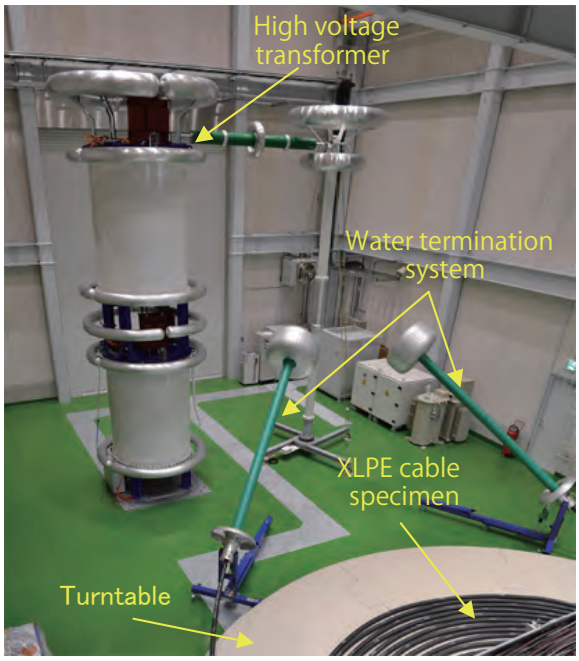


Photo: Long Length XLPE Cable Deterioration Testing System

High-Power Test Facilities: Renewal of Outdoor Disconnectors

Background

High-power test facilities are used for short-circuit tests of circuit breakers and high power arc tests of insulator sets, power cables, and transformers to ensure their safety and performance. Outdoor disconnectors are used to connect transformers and terminals in test yards and are required for high current flow of 80kA. To maintain the testing ability of high-power test facilities, outdoor disconnectors installed in 1963 were renewed.

Outline

Outdoor disconnectors were used to flow short-circuit currents from transformers to test yards. The outdoor disconnectors are used in combination to suit test voltages and currents.

Specifications

(1) Disconnectors
  (a) 115kV Vertical Break disconnector
    Open-close mechanism: One pole vertical break, Operating mechanism: motor drive (50Hz, 200V)
    Rated short time withstand current: 100kA rms, 2s, 250kA peak
    Rated voltage: 115kV, Rated current: 4000A, Number: 26
  (b) 115kV Horizontal Break disconnector
    Open-close mechanism: Double side horizontal break, Operating mechanism: motor drive (50Hz, 200V)
    Rated short time withstand current: 50kA rms., 2s, 125kA peak
    Rated voltage: 115kV, Rated current: 4000A, Number: 3 (3-unit interlock operation)
  (c) 23kV disconnector
    Open-close mechanism: One pole vertical break, Operating mechanism: motor drive (50Hz, 200V)
    Rated short time withstand current: 20kA rms., 2s, 50kA peak
    Rated voltage: 23kV, Rated current: 800A, Number: 4 (Three pole: 1, single pole: 3)
(2) Control system
  Renewal outdoor disconnector control software
(3) Supervisory system
  Installation of video camera system for supervisory of disconnector contacts

[Installed location and date]

Yokosuka area / February, 2013

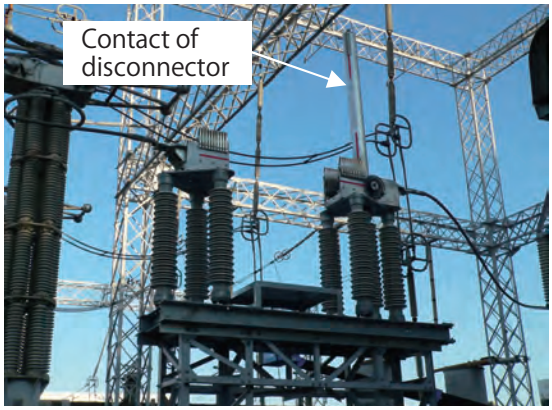


Photo 1: 115kV Vertical Break disconnector (Open)

Photo 2: 115kV Horizontal Break disconnector (3-unit interlock operation)

Improvement of Atom Probe Systems by Addition of Short Wavelength Laser Equipment

Background

More accurate methods to predicting aging changes in structural materials are needed in the face of reoperation and long-term operation of light water reactors. We have established an analysis station for nuclear materials in a radiation controlled area and utilized it for developing the embrittlement correlation code based on investigation of the irradiation embrittlement mechanism of reactor pressure vessel steels. This improvement by adding short wavelength laser equipment to the existing atom probe allows us to analyze the place of interest difficult to observe in the past such as the analysis of extra small amounts of elements at the grain boundary.

Outline

The existing high resolution atom probe system located in the radiation controlled laboratory in the Komae area was upgraded to the high resolution laser-assisted three dimensional atom probe system with the highest quality level of mass resolution and spatial resolution in the world by the addition of short wavelength laser equipment. The improved system allows us to easily observe samples with the oxidization film difficult to observe with the former laser equipment and has the advantage of improved analysis efficiency due to the shorter time taken for data acquisition. In addition, the system allows us to analyze ultra-fine precipitates and grain boundary segregation as well as extra small amounts of elements better than the former equipment since it can minimize the effect of laser power deposition on the microstructure in the target material and also has a detector with high mass resolution. This is the first installation of an atom probe system with similar laser equipment in a radiation controlled area.

Specifications

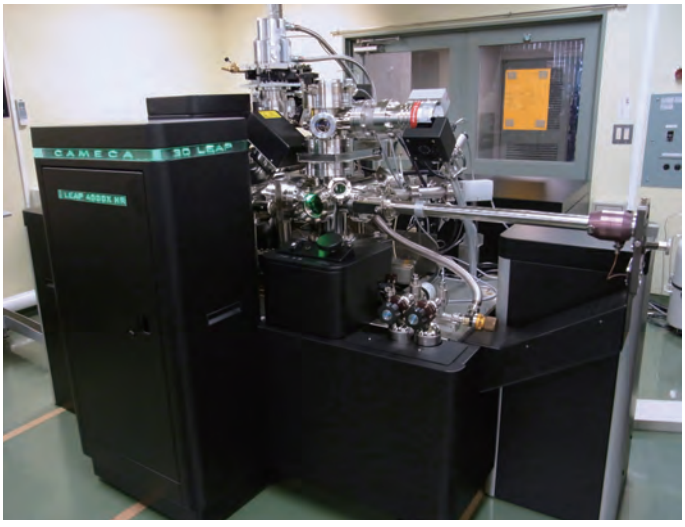
The improved atom probe system has the following advantages.

- The ultraviolet (355nm) laser and widely variable laser power (several fJ – 1.0nJ) enable analysis of a wide variety of materials with a high success rate.
- The minimization of the spot size of a laser beam less than 3μm makes it possible to obtain a mass-to-charge spectrum with very high resolution.
- The laser pulse rate of 250kHz in maximum makes it possible to acquire data in a shorter length of time. data acquisition.

[Installed location and date]

Komae area / March, 2013

Short wavelength laser oscillator (left side view)



Appearance of three dimensional atom probe (front view)

Photos: Three dimensional atom probe system equipped with a short wavelength laser

Electron Probe Micro Analyzer (EPMA) for Radioactive Materials

Background

More accurate methods to predicting aging changes in structural materials are needed in the face of reoperation and long-term operation of light water reactors. We have established an analysis station for nuclear materials in a radiation controlled area and utilized it for developing the embrittlement correlation code based on investigation of the irradiation embrittlement mechanism of reactor pressure vessel steels. This facility is able to obtain the chemical composition of materials with a high accuracy in large areas up to an order of centimeter and also broadens the spatial scale able to be analyzed in the analysis station.

Outline

This facility allows us to analyze the chemical composition in a large observation area of radioactive materials due to the installation of an electron probe micro analyzer (EPMA) equipped with a field emission gun and ultra-soft X-ray detector in the radiation controlled laboratory in the Komae area. The inclusion of a 100nm minimum and the segregation at the grain and other boundary can be sensitively analyzed using the field emission gun, and light elements such as boron, carbon, and nitrogen can also be sensitively analyzed using the ultra-soft X-ray detector. For example, it is useful to investigate the effect of light elements on mechanical properties due to the fact it can analyze at a level of tens of ppm in boron in steels. It also has the advantage of large scale analysis from nanometer to centimeter by the effective combination of nanometer scale analysis techniques such as atom probe and TEM utilizing an array of equipment in the analysis station.

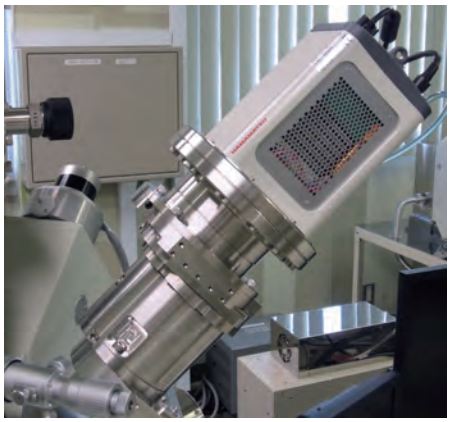
Specifications

The specifications of this EPMA are summarized as follow.

- Main body: JEOL JXA-8530F
  - Electron gun: Schottky field emission gun
  - Spatial resolution of secondary electron: < 3nm
- Detectors:
  - Wave dispersive X-ray detector: 5
  - Energy dispersive X-ray detector: 1 (silicon drift type)
  - Ultra-soft X-ray detector: 1 (diffraction grating and cooled CCD)
  - Range of energy spectrum: 50 – 210eV

[Installed location and date]

Komae area / December, 2012



Ultra-soft X-ray detector

Photos: Electron probe micro analyzer (EPMA) for radioactive materials

4. Activities

4. Activities

The activities of the CRIEPI in FY 2012 are outlined below.

1 Human Resources

The CRIEPI employs 825 people as of 31st March, 2013. 726 people are employed in research fields while 99 people are involved in clerical work. Fig. 1 shows the breakdown of researchers working in diverse fields. 380 people working at the CRIEPI have a Ph.D. Of these, 75% and 10% have an engineering and science background respectively.

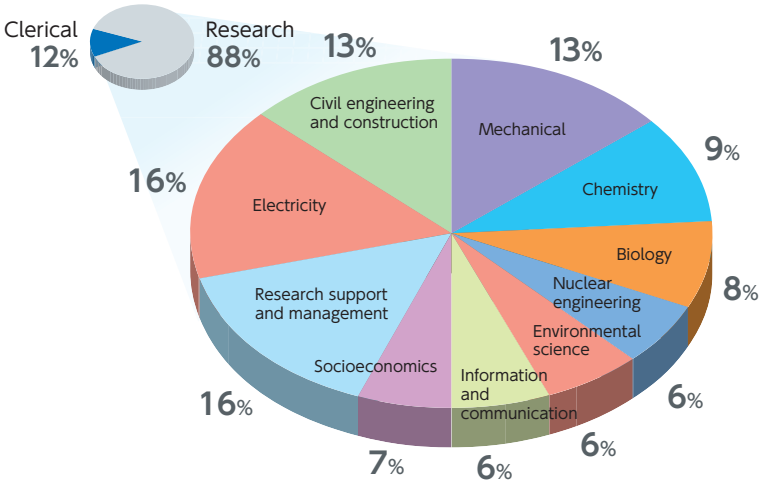


Fig. 1: Staff breakdown

2 Research Reports

A total of 429 CRIEPI research reports were produced in FY 2012. Of these, 271 were research reports and 158 were reports on funded research by electric power companies, the central government and others. Fig. 2 shows the breakdown of reports by subject field. The titles of the research reports, etc. which are publicly accessible are listed in Appendix (1). The body text of these research reports and corresponding leaflets*1 can be downloaded from the CRIEPI's website.

*1 The timing of leaflet publication may differ from the publication timing of the corresponding report.

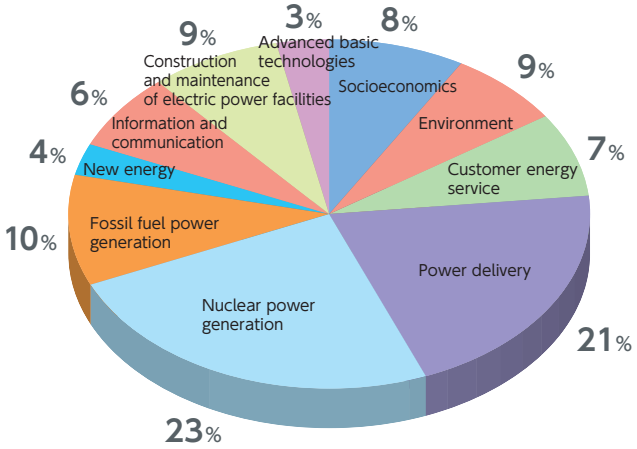


Fig. 2: Breakdown of reports by subject field

3 Presentation of Research Papers

A total of 1,559 research papers were presented in bulletins of academic societies and academic journals and at academic conferences. Of these, 383 papers were peer reviewed. Fig. 3 shows the breakdown of research papers by subject field. The titles of these papers are contained in the research paper database under "Research Results/Reports, etc." on the CRIEPI's website.

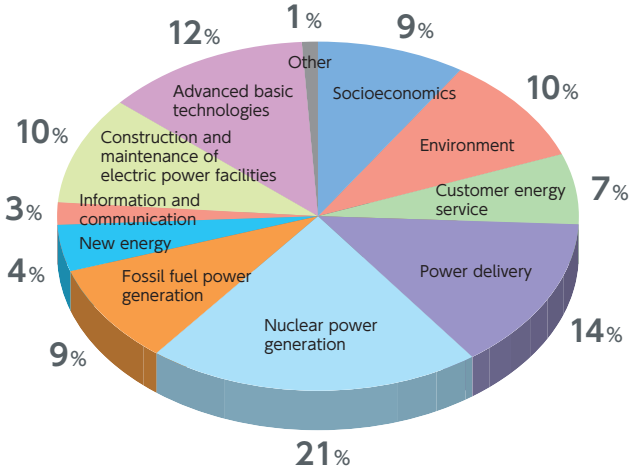


Fig. 3: Breakdown of research papers by subject field

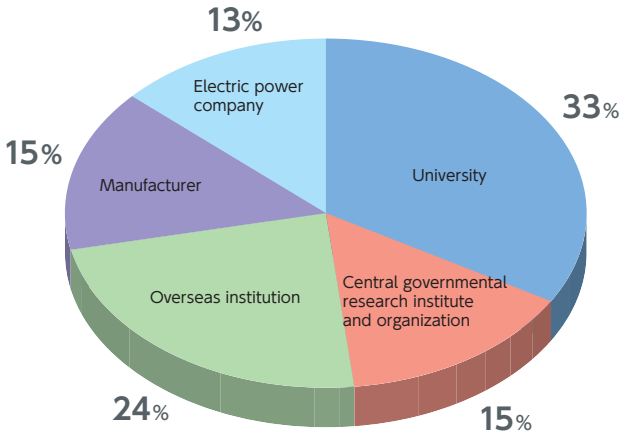


Fig. 4: Classification of research partners

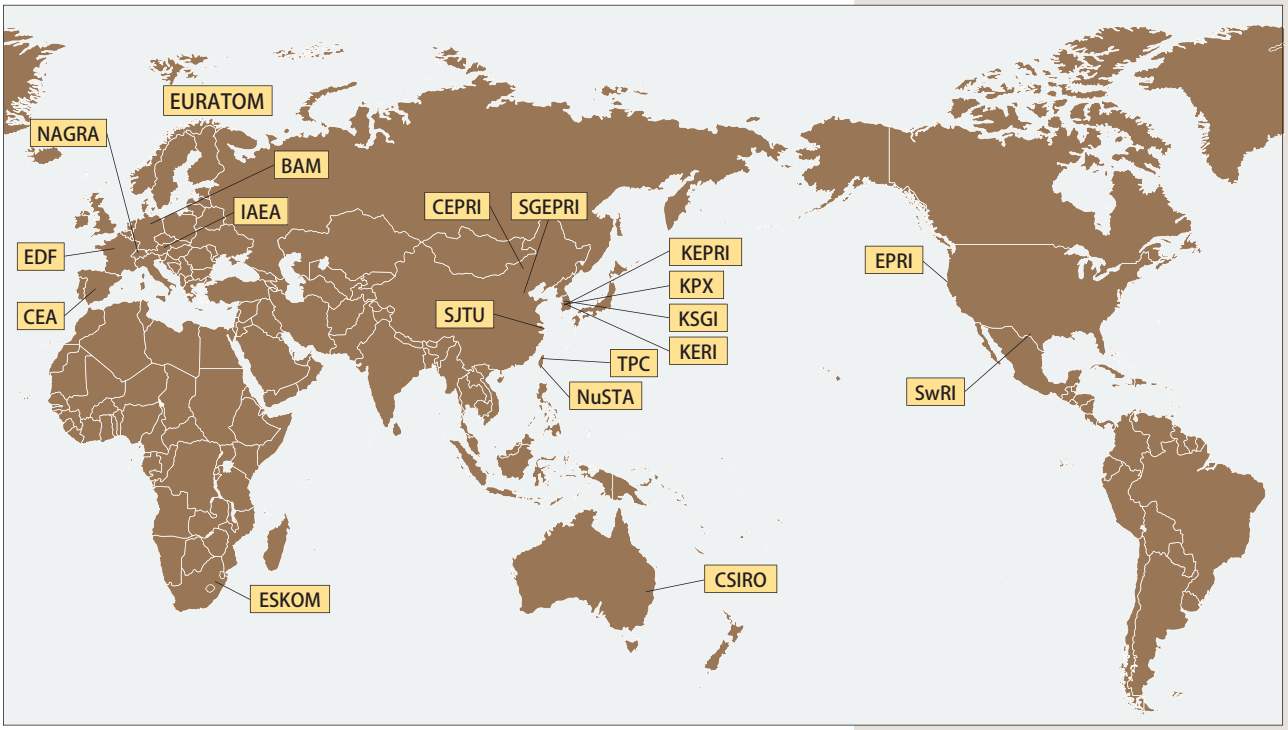


Fig. 5: Main partners for research cooperation

The European Atomic Energy Community (EURATOM) is based in Europe.

4 Research Cooperation / Interchanges

4-1 Joint Research

A total of 196 joint research projects were conducted in FY 2012. As shown in Fig. 4, universities and central governmental research institutes, etc. accounted for 33% and 15% of the research partners respectively.

4-2 Main International Cooperation/ Interchange Schemes

The CRIEPI has been moving ahead with joint research, information exchange and human interaction with a number of research institutes overseas. Fig. 5 shows the main overseas institutes with which the CRIEPI has concluded an international agreement for cooperation. Table 1 (p.98) lists the main partners of the CRIEPI for international cooperation / interchange.

4. Record of Activities The following is a summary

Table 1 Main International Cooperation/Interchange Partners

Main Partners for Research Cooperation

Asia

Korea Electric Power Research Institute (KEPRI)
Korea Electrotechnology Research Institute (KERI)
Korea Power Exchange (KPX)
Korea Smart Grid Institute (KSGI)
Taiwan Power Company (TPC)
Nuclear Science and Technology Association of Taiwan (NuSTA)
China Electric Power Research Institute (CEPRI)
State Grid Electric Power Research Institute (SGEPRI), China
Shanghai Jiao Tong University (SJTU), China

USA

Electric Power Research Institute (EPRI)
Southwest Research Institute (SwRI)

Europe

European Atomic Energy Community (EURATOM), EU
National Cooperative for the Disposal of Radioactive Waste (NAGRA), Switzerland
French Atomic Energy Commission (CEA)
Électricité de France (EDF)
Federal Institute for Materials Research and Testing (BAM), Germany
International Atomic Energy Agency (IAEA)

Oceania

Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia

Africa

ESKOM, South Africa

Main Partners for Joint Research in Progress

Asia

Taiwan Power Research Institute (TPRI)
Korea Atomic Energy Research Institute (KAERI)
Korea Institute of Nuclear Security (KINS)
Korea University

North America

Electric Power Research Institute (EPRI)
Idaho National Laboratory (INL)
National Center for Atmospheric Research (NCAR)
New Mexico Institute of Mining and Technology (NMT)
United States Department of Energy (DOE)
United States Nuclear Regulatory Commission (USNRC)
National Institute of Standards and Technology (NIST)
Nuclear Waste Management Organization (NWMO), Canada
Atomic Energy of Canada Limited (AECL)

Europe

French Atomic Energy Commission (CEA)
Électricité de France (EDF)
National Agency for Radioactive Waste Management (ANDRA), France
Institute de Radioprotection et de Sûreté Nucléaire (IRSN), France
Swedish Nuclear Fuel and Waste Management Company (SKB)
Studsvik Nuclear, Sweden
The Von Karman Institute for Fluid Dynamics (VKI), Belgium
Studiecentrum voor Kernenergie - Centre d'étude de l'Energie Nucléaire (SCK・CEN), Belgium
National Cooperative for the Disposal of Radioactive Waste (NAGRA), Swizerland
VTT Technical Research Centre of Finland
POSIVA, Finland
Radioactive Waste Repository Authority (RAWRA), the Czech Republic
Comenius University in Bratislava, Slovakia
International Atomic Energy Agency (IAEA), Austria
Organization for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA)
European Atomic Energy Community (EAEC/EURATOM), EU
Institute for Transuranium Elements (ITU), Germany
Forschungszentrum Karlsruhe GmbH (FZK/INE), Germany
Gesellschaft für Nuklear-Service mbH (GNS), Germany
Gesellschaft für Anlagen – und Reaktorsicherheit mbH (GRS), Germany
Federal Institute for Materials Research and Testing (BAM), Germany
Forschungszentrum Dresden-Rossendorf (HZDR), Germany
Federal Ministry of Economics and Technology (BMWi), Germany
Leibniz Institute for Solid state and Materials Research (IFW), Dresden, Germany
Friedrich Schiller University Jena, Germany
Polytechnic University of Turin, Italy
National Research Council, Italy
University of Twente, Netherlands
Nuclear Research and Consultancy Group (NRG), Netherlands
Institute for Energy Technology (IFE), Norway

Oceania

Curtin University, Australia

Other (involvement of institutes from multiple countries)

Mont Terri Consortium
Halden Reactor Project

Participation in International Organizations

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

of the activities that the CRIEPI was engaged in FY 2012.

5 Forums, Seminars and Other Events

The following forums, seminar and open laboratory were organized in FY2012.

●CRIEPI Forum 2012 (special version-<part Ⅱ>)
What should we do the preparation of the electric power facility for an earthquake and a tsunami?
May 11th, 2012, IINO Hall, Tokyo

●Open Laboratory
May 20th, 2012, Akagi Testing Center
October 13th, 2012, Komae Area
October 13th, 2012, Abiko Area
October 20th, 2012, Yokosuka Area

6 Industrial Property Rights

129 patents were registered and 119 patent applications were made in FY 2012. 20 patents or know-how*2 were newly licensed in FY 2012.

7 Software

The CRIEPI has its own software registration system for the management of copyright. A registered software may be licensed to electric companies, other profit-making enterprises and universities in response to their request. The number of new software registrations and the number of new licenses awarded were 67 and 357 (1077 copies) respectively.

8 Other

The CRIEPI or its executives and regular employees wrote or edited 8 major books in FY 2012 while executives and regular employees received external awards on 45 occasions (total of 65 persons). The "CRIEPI's World Wide Information Service" (http://criepi.denken.or.jp/) is a free and publicly accessible service that has been running since FY 1995. Although the above sites are offered in Japanese, the CRIEPI also offers an English language site with wealth of information. (http://criepi.denken.or.jp/en/index.html)

They provide access to the summaries of a number of non-confidential research documents and annual research reports, as well as publications such as the "CRIEPI News" (http://criepi.denken.or.jp/research/news) which is a series of leaflets that uses plain language, photographs, and illustrations to introduce the research findings of the CRIEPI in a way that is easy for the general public to understand.

*2 This figure is based on the number of actually licensed intellectual property rights and know-how.

Locations

Otemachi Area

- Head Office
- Socio-economic Research Center

1-6-1 Otemachi, Chiyoda-ku, Tokyo 100-8126
Phone: +81-3-3201-6601
Tokyo Metro Otemachi Station, Exit C7

Komae Area

- Center for Intellectual Property & Technology Licensing
- System Engineering Research Laboratory
- Nuclear Technology Research Laboratory
  - Radiation Safety Research Center
  - Human Factors Research Center
- Komae Operation & Service Center
- Administrative Support Center

2-11-1 Iwadokita, Komae-shi, Tokyo 201-8511
Phone: +81-3-3480-2111
7 minutes walk from Kitami Station
[Odakyu line]

Abiko Area

- Civil Engineering Research Laboratory
  - Nuclear Fuel Cycle Backend Research Center
- Environmental Science Research Laboratory
- Abiko Operation & Service Center

1646 Abiko, Abiko-shi, Chiba 270-1194
Phone: +81-4-7182-1181
20 minutes walk from Abiko Station
[JR Joban line] (shuttle bus available)

Yokosuka Area

- Electric Power Engineering Research Laboratory
  - High Power Testing Laboratory
- Energy Engineering Research Laboratory
- Materials Science Research Laboratory
  - PD Center
- Yokosuka Operation & Service Center

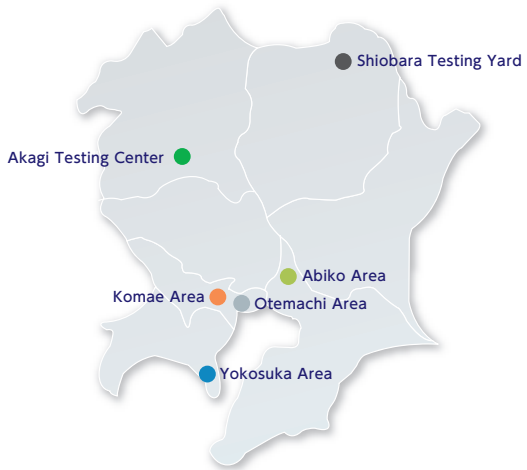
2-6-1 Nagasaka, Yokosuka-shi,
Kanagawa 240-0196
Phone: +81-46-856-2121
Approx. 35 minutes by bus from Zushi Station
[JR Yokosuka line]

Akagi Testing Center

2567 Naegashima-machi, Maebashi-shi, Gunma 371-0241
Phone: +81-27-283-2721
Approx. 40 minutes by taxi from Maebashi Station
[JR Ryomo Line]

Shiobara Testing Yard

1033 Sekiya, Nasushiobara-shi, Tochigi 329-2801
Phone: +81-287-35-2048
Approx. 30 minutes by taxi from Nasushiobara Station
[Tohoku Shinkansen]



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Central Research Institute of Electric Power Industry (Planning Group)
1-6-1 Otemachi, Chiyoda-ku, Tokyo 100-8126 JAPAN
Tel.+81-3-3201-6601 Fax.+81-3-3287-2841 E-mail▸www-rdd-ml@criepi.denken.or.jp URL▸http://criepi.denken.or.jp/