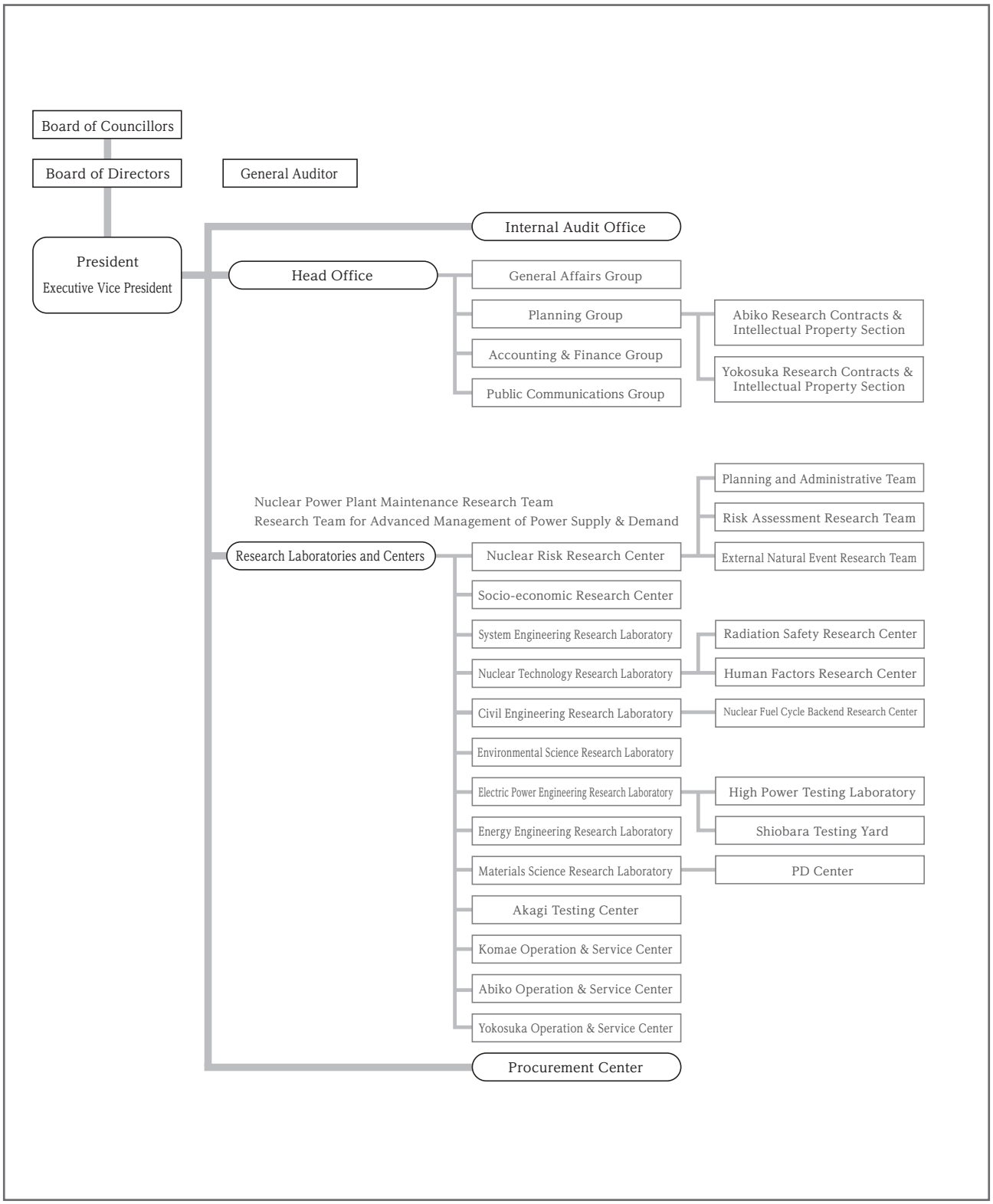
Central Research Institute of Electric Power Industry

Annual Research Report Fiscal Year 2014

CRIEPI
Central Research Institute of Electric Power Industry

Organization of the Central Research Institute of Electric Power Industry



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1. Outline of Research Activities

1. Outline of Research Activities

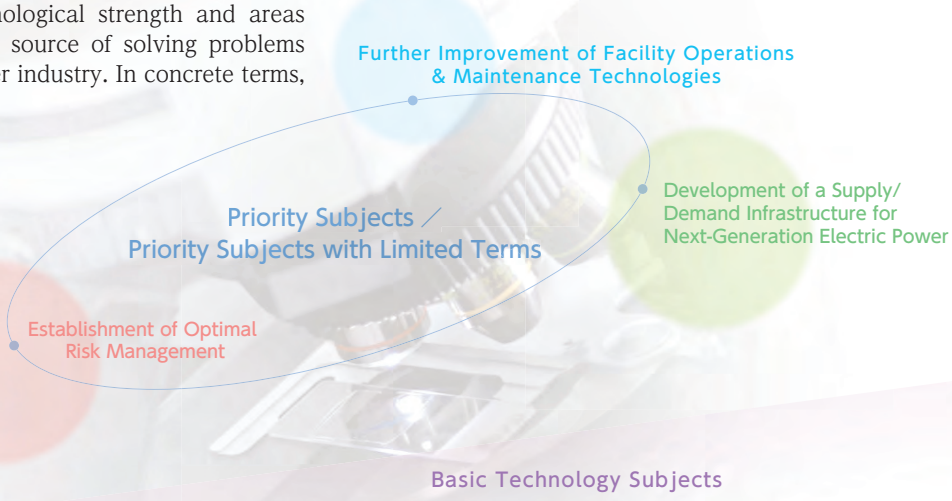
CRIEPI conducted research aimed at the development of technologies essential to a stable power supply in the future as well as to prepare for the increase in risks in order to provide a stable supply of power, which is the foundation of Japan's economic activity. This research was conducted under the "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". In concrete terms, CRIEPI leveraged its collective strength and took priority action to address the pressing issues of the electric power industry, namely, safety assessments of nuclear power plants against the natural external factors of earthquakes, tsunamis, tornados and so on as well as responding to investigations verifying conformity with new regulatory standards.
Moreover, we proceeded steadily with the development of equipment diagnosis and life assessment technology for the efficient maintenance and renewal of power generating and power distribution equipment as well as technological developments to respond to changes in the power networks, such as increased introduction of renewable energy and more activity on the demand side.

Of the technologies believed to be essential now or in the future to the electric power industry, CRIEPI has selected 35 priority subjects to maintain and develop. Of these priority subjects, CRIEPI focused its collective strength particularly on resolving 10 priority subjects with limited terms which were believed to be urgent and, consequently, produced solid results. Priority subjects and priority subjects with limited terms for which collaboration was deemed necessary were grouped into 11 categories and research in these areas was conducted effectively. Furthermore, 35 basic technology subjects were established and through action leveraging the characteristics and expertise of eight 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 FY2014 are described in Chapter 2 (Major Research Results). This chapter lists the different priority subjects addressed by each project subject, the basic technology subjects addressed by each specialized research laboratory, and the respective aims of each subject.

Regarding large-scale research facilities essential to solving issues faced by the electric power industry and in order to maintain and advance CRIEPI's research capability and problem-solving capacity, the following actions were implemented; renewal of CRIEPI' generator simulator, the power system simulator, which can analyze power system phenomenon in a near-real environment with high accuracy, introduction of an experimental facility for simulated rod bundle cooling of light-water nuclear reactors which can visualize the cooling state inside fuel bundles, installation of a strong shake generator which enables performance assessment of nuclear power plant devices against large accelerations in the vertical direction, addition of a unidirectional shaking table on a dynamic geotechnical centrifuge to evaluate stability of the subsurface structure of nuclear power plants and the surrounding slopes during an earthquake, redevelopment of DC test lines and related facilities to measure the electrical environment of real-scale DC transmission lines, battery performance evaluation and materials production facilities for the evaluation of rechargeable lithium-ion battery materials production and evaluation facilities and production/evaluation of battery materials.

*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 FY2014 (31st March, 2015)

Priority Subjects ／ Priority Subjects with Limited Terms

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

Establishment of Optimal Risk Management

Nuclear Power Plant Safety
- ○Safety Assessment of LWR Systems
- ○Assessment of Radioactive Material Diffusion and its Environmental Impact Evaluation
- ○Establishment of Methodologies to Evaluate Fires in Nuclear Facilities
- ○Assessment of Fragility of Nuclear Facilities due to External Natural Events
- ○Assessment for the Effects of Natural Hazards on Nuclear Facilities

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

Nuclear Fuel Cycle and Backend Technologies
- ・Development and Systematization of Long-term Safety Assessment Technologies for Radioactive Waste Disposal
- ・Development of Long-Term Storage Management Technologies for Spent Fuel

Natural Disaster Reduction on Transmission and Distribution Facilities
- ・Development of Prediction Methods for Weather/Climate Impact on Electric Power Facilities
- ・Establishment of Protective Measure Technologies against Damages to Overhead Transmission and Distribution Facilities Caused by Wind and Snow
- ・Development of Lightning Risk Management Schemes

Energy and Environment Institutions
- ○Well-functioning Electricity Market and Network Neutralization
- ・Social and Institutional Analysis of Nuclear Business Environment in Japan
- ・Climate Change Policy
- ・Scientifically and Economically Rational Scenarios for Reducing CO_2 Emissions

Further Improvement of Facility Operations and Maintenance Technologies

Nuclear Power Plant Maintenance
- ・Structural Integrity Evaluation of Reactor Pressure Vessels and Core Internals
- ・Evaluation of Components and Piping Integrity in LWRs
- ・Evaluation of Insulation Properties of Cables Used in Nuclear Power Plants
- ・Development of Nondestructive Inspection Technologies for Components and Piping in Nuclear Power Plants

Construction, Operation and Maintenance of Power Generation Facilities
- ○Development of Life Assessment Technology for High Temperature Structural Components of High Chromium Steels
- ・Development of Assessment Techniques for Comprehensive Impact of Thermal Power on Atmospheric Environment
- ・Development of Technologies for Increasing Use of Coal Ash
- ・Development of Efficient Impact Assessment Methods for Ecosystems
- ・Synthesis System of Numerical Analysis for Current and Sediments in River and Reservoirs

Operation and Maintenance of Transmission and Distribution Facilities
- ○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

Next-generation Thermal Power Technologies
- ・Improvement of Operation and Control Technologies to Diversify Fuel Types for Pulverized Coal-fired Power Plants
- ・Improvement of Utilization Technology for Low-Grade Energy Resources

Next-generation Power Grid Technologies
- ・Assessment of System Security with High Penetration of Photovoltaics
- ・Development of Precise Power Output Estimation and Prediction Techniques of Photovoltaic Power Generation
- ・Development of ICT Infrastructure Building Techniques Based on General-purpose Communication Technology
- ・Development of Technologies for Next-generation Power Distribution Networks
- ・Assessment of the Value of Next-generation Demand Management

Energy Utilization Technologies
- ○Development and Evaluation of Advanced Heat Pumps
- ・Establishment of Evaluation Technologies for High Performance Secondary Batteries

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
- ◆Communication 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
- ◆Bioengineering
- ◆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
- ◆Structural Materials
- ◆Advanced Functional Materials
- ◆High Performance SiC Semiconductor for Power Electronics
- ◆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**

Safety Assessment of LWR Systems

Background and Objective

To increase the safety of a nuclear power plant, it is necessary to take measures such as remodeling and adding equipment which can improve safety by revealing vulnerabilities through performing simulations and probabilistic risk assessments (PRA) which can grasp detailed phenomena. In regards to this issue, we will enhance the technique for evaluating the effectiveness of safety improvement measures, and contribute to continual improvement of the safety of nuclear power plants by using this technique.

Main results

1 Development of a Seismic PRA model[*1]

NRRC has been improving the methods for seismic evaluation and fragility evaluation. NRRC has also been developing a seismic accident sequence model for the target plant (Fig. 1). The objective of these research activities is to conduct seismic PRA. Furthermore, NRRC has been quantifying CV Failure Frequency and developing a model for source term evaluation. The trial seismic PRA for the target plant (an actual NPP) demonstrated the feasibility of evaluating relative vulnerabilities according to seismic acceleration and effectiveness of SA countermeasures.

2 Development of Probabilistic Risk Analysis Library

In a level 1 PRA that assesses core damage frequencies, fault trees/event trees (FT/ET) are typically utilized. To validate numerical accuracy in the assessment, we developed a new library which can analytically evaluate success paths in ETs without approximation errors using Binary Decision Diagrams. Since this library can evaluate analytic sequence occurrence frequencies, approximation errors in the minimal cut set method which is commonly used in a PRA can be quantified (Fig. 2). Hence, this library can accurately perform a seismic PRA, which previously had potential large numerical errors due to the minimal cut set method (O14001).

3 Development of a PRD method applied to level-2 PRA[*1]

A method of Phenomenological Relationship Diagram (PRD) is applied to the quantification of probabilities of core damage events identified in the containment event tree (CET) used in the level-2 PRA, which evaluates frequencies of the release rate of fission products during the containment failure. The PRD evaluates a probability of the core damage phenomenon selected as a top-event of the CET, and is expanded to the lower component event by employing cause relations described by physical equations. The probability of the top-event can be obtained by piling up the probabilities of the lowest elementary event combined by physical equations. In this study, the PRD is applied to the re-criticality events considered during the core damage. It is found that the PRD can quantitatively evaluate probabilities to non-linear phenomena such as effective multiplication factors and reactivity insertion rates which determine the released energy during the re-criticality event.

4 Evaluation of transient critical heat flux simulated reactivity initiated accident (RIA)

RIA is a phenomenon in which reactor power rapidly increases due to control-rod fall etc. Since the cooling limit of the fuel rod during RIA is defined by the critical heat flux on the fuel rod surface in a transient state, it is important to evaluate a transient critical heat flux. To evaluate this, experimental apparatus was designed and manufactured to evaluate the transient critical heat flux under low pressure conditions with a rod bundle heated by direct current heating (simulated fuel rod bundle with fuel rods arranged in rattice pattern) (Fig. 4a). The transient critical heat flux was evaluated in the range of initial water temperature and flow rate assumed during RIA under low pressure condition, and an experimental database of the transient critical heat flux in consideration of cross-flow and outer wall effects was constructed.

*1 The research activity is a part of the publicly offered research on PRA sponsored by METI.
*2 Phenomenological Relationship Diagram: The method of calculating the probability of the ET branch that describes the physical chemistry phenomenon.

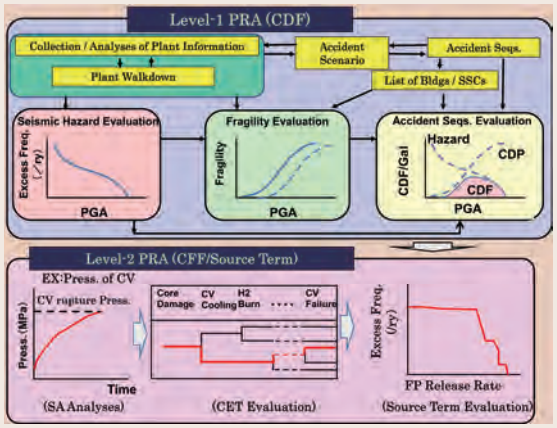


Fig. 1: Outline of seismic PRA method

Seismic PRA evaluates seismic hazard based on seismic characteristics, fragilities of buildings & SSCs based on seismic capacities & responses, accident sequence evaluation with the results of seismic hazard / fragility evaluation, CFF & source term evaluation based on frequencies of PDSs quantified in accident sequence evaluation using CET and severe accident analyses. With the results of these evaluations, it is possible to identify relative vulnerabilities and to evaluate effectiveness of countermeasures. Since these results are inputs to risk informed decision makings, it is important the results are provided by evaluation models faithful to plant conditions.

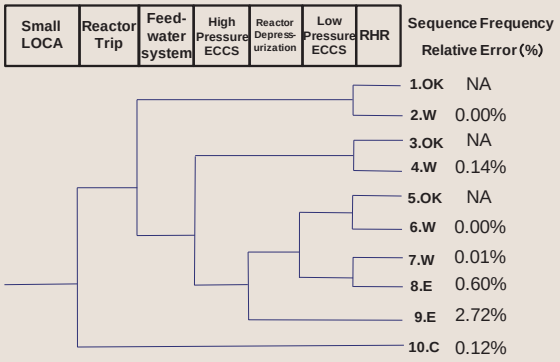


Fig. 2: Numerical Errors in small LOCA model with the minimal cut set method

Small LOCA is a loss-of-coolant accident resulting from rupture of a small pipe. By analyzing an FT/ET model for small LOCA using the minimal cut set method and the binary decision diagram, we quantified numerical errors in the minimal cut set method. We verified that numerical errors in this model, which stems from an approximation in the minimal cat set method, are small and this small LOCA model is evaluated accurately.

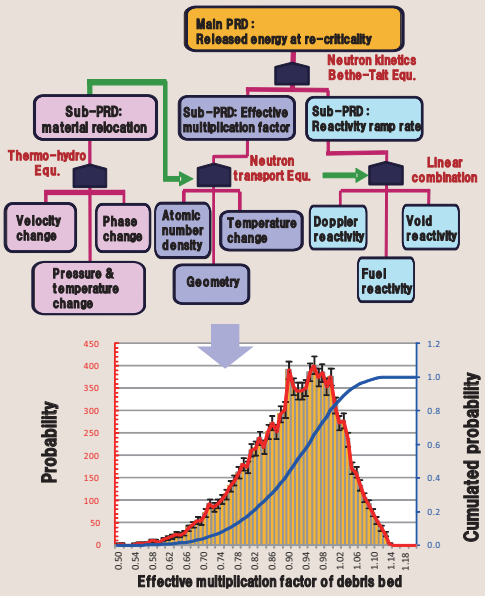


Fig. 3: PRD to evaluate the probability of re-criticality events during severe accidents

The PRD evaluating the probability of released energy during a re-criticality event consists of three sub-PRDs describing material relocation, effective multiplication factor, and reactivity insertion rate for debris beds (upper part of the figure). The probability distribution function (PDF), shown in the lower part of the figure, of the effective multiplication factor of debris beds is determined by PDFs of the particle diameter (geometry), porosity (material relocation), and uranium/metal ratio (atomic number density) of the debris bed, based on the neutron transport equations as the cause relation between elementary events.

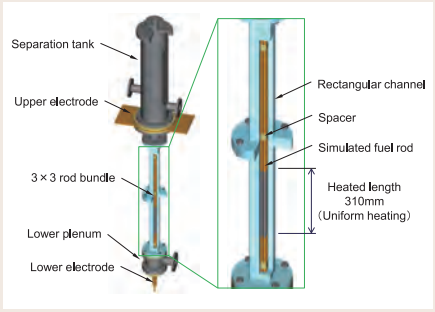


Fig. 4a: Experimental apparatus of RIA under low pressure condition

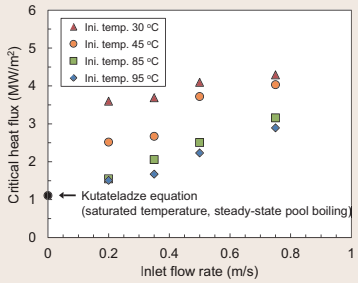


Fig. 4b: Transient critical heat flux during RIA under low pressure condition

The experimental apparatus was designed and manufactured to evaluate a transient critical heat flux (Fig. 4a). The 3×3 rod bundle simulating BWR fuel rod bundle was uniformly heated by direct current and the transient critical heat flux was evaluated by the temperature elevation of simulated fuel rod. The experimental data was acquired in the range of initial water temperature and flow rate assumed during RIA under low pressure condition. The results show that the transient critical heat flux increased with the decrease of initial water temperature, or the escalation of flow rate.

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

Assessment of Radioactive Material Diffusion and its Environmental Impact Evaluation

Background and Objective

In order to evaluate and continuously improve the safety of nuclear power plants, it is necessary to carry out preliminary assessments of the environmental impact of radioactive materials on the atmosphere and ocean in the case of severe accidents, as well as the effectiveness of preventive measures against nuclear power plant accidents. The target of this study is to develop techniques for predicting the dispersion of radioactive materials into the atmosphere and ocean, 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 via the assessment of environmental impact.

Main results

1 Prediction of atmospheric dispersion of radioactive materials emitted from nuclear power plants

A coupled model of meteorological and atmospheric dispersion models has been developed to predict near-field-scale dispersion of radioactive materials emitted from nuclear power plants. The model has a fine computational grid in units of hundred meters, and is validated with a series of observation data from a field tracer experiment. The model predicts axial surface concentrations*1 with satisfactory accuracy for almost all atmospheric conditions (Fig. 1) (O14004). We have also conducted a survey on the case examples of probabilistic risk assessment (level 3 PRA) conducted in the U.S. and Europe. Issues and future tasks of level 3 PRA were summarized through the survey for its application in Japan.

2 Developing techniques for the assessment of radioactive material oceanic dispersion and transfer to marine organisms

We developed an oceanic dispersion model and transfer model to marine organisms and sediment in order to assess the impact of radioactive materials on a marine environment. The oceanic dispersion model simulated the reduction of ^{137}Cs activity in seawater for three and half years [1]. The simulation of ^{137}Cs transfer to marine sediment estimated that the total amount in marine sediment was less than 10% of the total amount in seawater (Fig. 2) [2]. The biological simulation demonstrated that the transfer of ^{137}Cs via prey organisms is likely to delay radionuclide depuration from demersal fish [3].

3 Development of a simple monitoring method for a specific environmental radioactivity using a cumulative gamma radiation dosimeter

A simple monitoring method was developed as an alternative to inconvenient conventional methods (e.g., GM survey meter) to observe radiocesium translocation/circulation in forest ecosystems [4] using a cumulative gamma radiation dosimeter (Fig. 3). Results showed the detection significance of a specific dose of boughs/trunks of Japanese cherry trees and cedar trees from the background was comparable to that of conventional methods, although the correlation between dose and radiocesium activity concentration was low. Further improvement is necessary to increase the correlation by considering the self-shielding effect of tree bodies and radiocesium distribution in the bodies (O14002).

*1 Maximum surface concentration of a tracer on an equidistance arc from a source.

[1] TSUMUNE DAISUKE, Isotope news, 729, 36-40, 2015. (In Japanese).
[2] MISUMI KAZUHIRO, et al., Journal of Environmental Radioactivity, 136, 218-228, 2014.
[3] TATEDA YUTAKA, et al., Journal of Environmental Radioactivity, accepted, 2015.
[4] Yoshihara et al., Journal of Environmental Radioactivity, 138: 220-226 (2014).

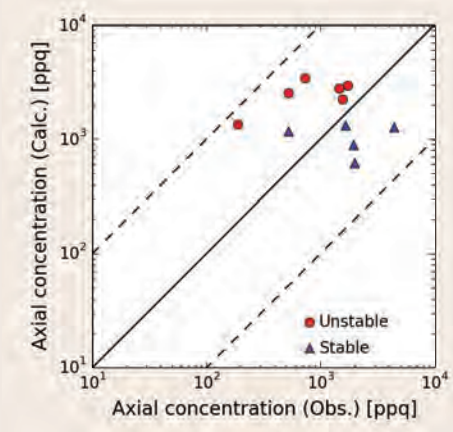


Fig. 1: Comparison of axial surface concentrations*1 (30 minutes average)

Observed and predicted axial surface concentrations on the equidistance arc of 1500 m from the source are compared. All data is plotted within the range of one tenth and ten times of the observation values under both the unstable and stable atmospheric conditions.

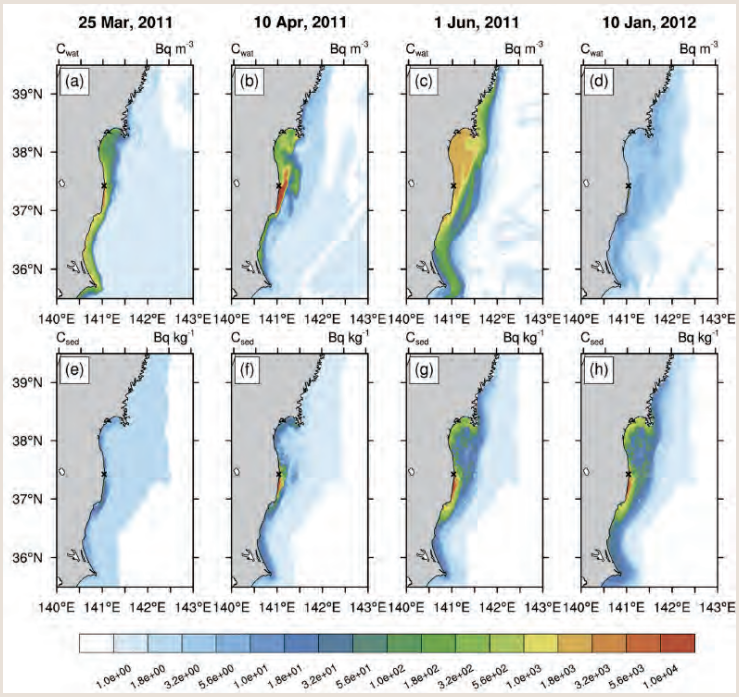


Fig. 2: Simulated ^{137}Cs activities in seawater and marine sediments

Simulated ^{137}Cs activities in seawater was reduced as a result of a decrease in direct release, however, simulated ^{137}Cs activities in sediment was increased due to transfer from seawater. Simulated values are in good agreement with observed values. Total amount of ^{137}Cs in sediment was estimated to be less than 10% of the total ^{137}Cs released into the ocean.

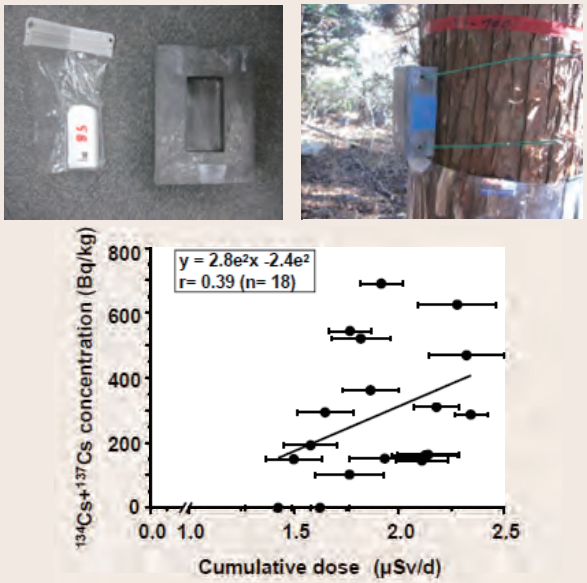


Fig. 3: A correlation between dose and radiocesium activity concentration by monitoring Japanese cedar trunks in a forest

Upper left: The cumulative dosimeter (D-shuttle, Chiyoda technol Co., Tokyo, Japan; 68×34×14 mm, 23 g) and the lead shield (3 cm thickness). Upper right: The attachment of the dosimeter in the shield on Japanese cedar. Bottom: A correlation between dose and radiocesium activity concentration observed under a contaminated BG (5.8 μSv/d).

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

Establishment of Methodologies to Evaluate Fires in Nuclear Facilities

Background and Objective

To obtain conformity on the new regulatory requirements for nuclear power plants, it is necessary to prepare fire prevention methodology with high accountability in accordance with the fire impact assessment guide enacted in June 2013. Furthermore, in order to reduce the risk induced by internal fire needed for the periodic safety review after recommencement of operations, continuous improvement of the fire hazard assessment and the fire prevention methodology is necessary.
In this project, we aim to evaluate the fire prevention methodology (fire extinguishing system, etc.) for nuclear power plants based on fundamental fire tests and confirm the validity of such methodology. In addition, to improve the accuracy of fire behavior prediction in accordance with fire source (such as cable fire, oil fire and electrical cabinet), we aim to integrate the fire hazard evaluation method and contribute to the establishment of scientific and rational countermeasures for fire prevention and internal fire PRA.

Main results

1 Establishing a construction method of an automatic foam fire extinguishing system for cable tray fires

Among the countermeasures to reduce the internal fire impacts of nuclear power plants, installation of the wet-type automatic fire extinguishing system with foam fire extinguishing agent (Fig. 1) may be applicable as automatic fire extinguishing equipment for cable tray fires. In order to establish an effective construction method for such a system, fire extinguishing tests were carried out using a ladder-type cable tray covered by the flame-proof sheet with 0.6 m width, and subjecting the inflammable high/low-voltage power cables to an overcurrent of 2 kA class (Fig. 2) in vertical and horizontal orientations. As a result, reliable fire extinction capability of the cooling and suffocation effect by foam fire extinguishing agent was confirmed and the prospect of applicability for actual installation obtained.

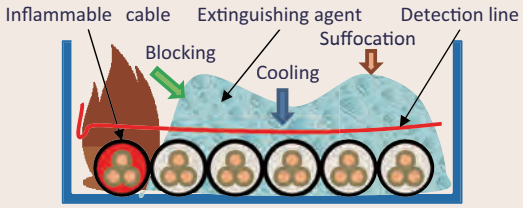
2 Clarification of limitations on the occurrence of High Energy Arcing Fault (HEAF) fires in low-voltage electric cabinets

Successive fire due to a HEAF event in the high-voltage metal-clad switch gear*1 was identified at the Onagawa nuclear power plant at the time of the Great East Japan Earthquake. As such, we tested a full scale low-voltage electric cabinet (power center) following high-voltage metal-enclosed switch gear, and confirmed that arcing energy above 19MJ induced the HEAF fire in the low-voltage electric cabinet with relatively content volume (Fig. 3). Based on these HEAF tests, we aim to reflect on the identification methodology of the zone of influence due to the HEAF fire and contribute to integration into the fire hazard evaluation.

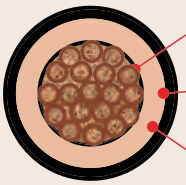
3 Establishment of an efficient methodology to predict air temperature in a compartment fire by the fire model

In fire hazard evaluation, in order to estimate the ignition time or damage time of important safety equipment, it is necessary to appropriately set the time change of heating power from heat source (heat release rates, HRRs). In the compartments of nuclear power plants, as the oxygen concentration around fire source may vary due to the air flow pattern by the ventilation system which may also be operated in the case of fire, HRRs may be highly dependent on the ventilation flow rate. In order to verify its dependency, fire tests in a single compartment were performed and the relationship between the oxygen concentration around fire sources and HRRs (Fig. 4) was clarified. In addition, through executing multiple compartment fire tests, we clarified the effect of the ventilation flow rate and the disposition of the air inlet/outlet duct on the air temperature and the heat balance in the compartments, and the heat transfer among compartments. Based on these test results, we aim to reflect on setting input conditions for fire models to reproduce the air temperature in the compartments and fire propagation scenarios, and finally contribute to the improvement of the fire PRA method.

*1 Installed in the metal enclosure with the protective relay (such as circuit breakers) and high-voltage bus to protect and control the power system.



[Extinguishing principle]

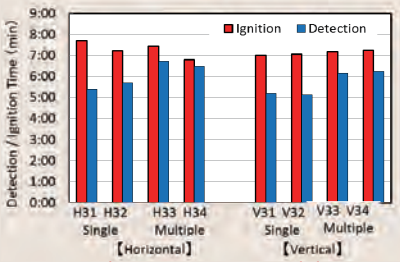


[Cross section of inflammable low voltage power cable]

Fig. 1: Example of an automatic foam fire extinguishing system for cable tray fires

An automatic foam fire extinguishing system is composed of a fire extinguishing agent cylinder, driving nitrogen cylinder, detection line, pipe and nozzle for agent injection, fire receiver etc. Foam suppression agent will be injected through the nozzles into the designated fire area and induce cooling and suffocation. Immediately after the short circuit of the detection cable at the activation temperature 90℃, the fire detection signal will be transferred to the fire receiver, and the fire extinguishing agent cylinder will be activated automatically. The allowable temperature is 90℃ for the continuous condition and 230℃ for the short-circuit condition for the inflammable low voltage power cable used in the fire tests (600 V, 100 mm^2, single core).

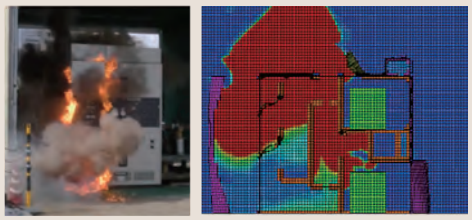
[Combustion after ignition and Operating conditions of foam fire extinguishing equipment]



[Comparison between ignition and detection time]

Fig. 2: Cable fire test apparatus with the overcurrent system

We confirmed that abnormal temperature conditions could be detected before the ignition in horizontal and vertical orientations by the S-shaped detection lines installed inside the cable tray. In addition, in the case of the horizontal cable tray, the foam suppression agent remained uniformly inside cable tray and succeeded in immediate suppression after injection. Similarly, in the case of the vertical cable tray, by the use of steel thin plates at intervals of 20 cm inside the steel cover attached to the cable tray, we verified the retention condition of the foam agent in the tray and its suppression capability.



[Examples of HEAF test with low voltage cabinet and simulation for zone of influence]

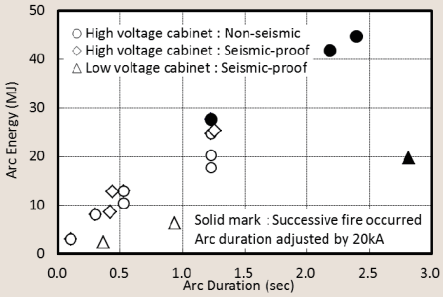
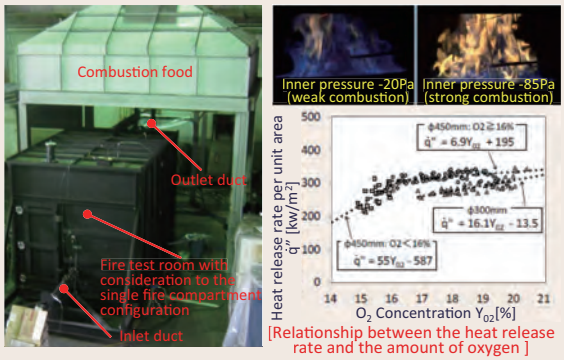


Fig. 3: Arcing energy measured in HEAF tests using low-voltage electric cabinets and the limitations of fire occurrence

We measured arcing energy* using 480 V class electric cabinets (three-phase three-wire system) under a condition with short circuit current around 20 kA and durations from 0.1 to 3.0 sec. When the arcing energy exceeded 19 MJ, a successive fire was identified on low-voltage electric cabinet with relatively low content volume rather than high-voltage metal-clad switch gear (executed in 2013).

*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 surrounding equipment.



[Relationship between the heat release rate and the amount of oxygen]

Fig. 4: Identification of heat release rate in a compartment under ventilation conditions

As the fire model gives spatial distributions of physical quantities, such as temperature, velocity, oxygen concentration, as well as their temporal variations, its output values are highly dependent on heat release rate and air ventilation rate. In order to clarify such a dependency, we executed pool fire tests with ethanol in a fire test room (width 2.4 m×Depth 3.6 m×height 2.4 m) with consideration to the single fire compartment configuration. As test parameters, various heat source areas (diameter 30, 45, 60 cm), locations (central), ventilation flows (0-100 m^3/h) and the disposition of the ducts 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 clarified the relationship between the heat release rate and the amount of oxygen entrained by fresh air. In addition, as a result of the fire test analysis by the fire propagation code, it is found that the air temperature in the fire compartment was appropriately predicted.

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

Assessment of Fragility of Nuclear Facilities due to External Natural Events

Background and Objective

The Fukushima Daiichi nuclear disaster wrought severe damage on the reliability of nuclear safety and societal trust. Most nuclear power plants are currently shut down for these reasons. Since nuclear power would play an important role for realizing a low carbon society, we should avoid long term shutdown. In this project the safety assessment methodologies for nuclear power plants subjected to natural disaster are studied.

Main results

1 Development of nonlinear time history response analysis method for the seismic stability evaluation of ground

A constitutive model for two-dimensional nonlinear time history response analysis was developed in order to evaluate the stability of rock slopes and the foundation of nuclear power plant during major earthquakes. The stress-strain relationship of this model was derived on the basis of a multi-spring model in plane strain state, and the influence of shear and tensile failure was considered. A numerical simulation of the dynamic centrifugal model test of slope was conducted for verification of the model. As a result, the timing of failure and residual displacements in the simulation were almost consistent with the model test (Fig. 1).

2 Stability evaluation methods of rubble mound breakwaters against tsunamis

In order to assess the strength of rubble mound breakwaters in nuclear power plants against tsunamis, a stability evaluation method of armor units in the breakwaters has been investigated [1]. Model-scale experiments, in which masses of armor units and overflow velocities were varied, were carried out and damages of the armor units were observed. The experimental results showed that the stability conditions of armor units against tsunamis were judged by the relationship between the mass of armor units and the overflow velocity (Fig. 2). Furthermore, a numerical method for evaluation of the overflow velocity was developed, and validated by experimental data.

3 Development of evaluation methods of tsunami hydrodynamic force and debris impact force

In order to develop the fragility evaluation methods of structures and components against tsunamis, large scale experiments on tsunami-induced loads were carried out using the Large-scale Tsunami Physical Simulator. The experiments on tsunami wave pressures on a seawall and a square column showed large, yet short-duration, pressures on the structures immediately after tsunami tips impacted the structures, and we proposed an estimation method for the impact pressures (Fig. 3) [2]. In order to obtain a dataset for verification and validation of the evaluation method of the tsunami-debris impact force, we carried out tsunami-debris impact experiments in which wood-logs and a real car were drifted in the tsunami inundation flow and impacted on a wall (Fig. 4) [3].

[1] T. Sakakiyama, J. JSCE, Ser. B2 (Coast. Eng.), 67, 791-795, 2011.
[2] N. Kihara et al., Coastal Engineering, 99, 46-63, 2015.
[3] D. Takabatake et al., J. JSCE, Ser. B2 (Coast. Eng.), 70, I_1491-I_1495, 2014.

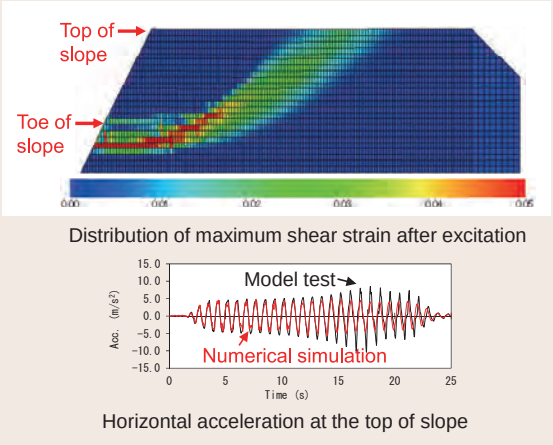


Fig. 1: Numerical simulation of dynamic centrifugal model test of slope (upper part: distribution of strain, lower part: comparison with the experiment of response acceleration)

A numerical simulation of the dynamic centrifugal model test of slope was conducted for verification of the nonlinear time history response analysis method. As a result, it was confirmed that the simulation results were relatively consistent with the model tests.

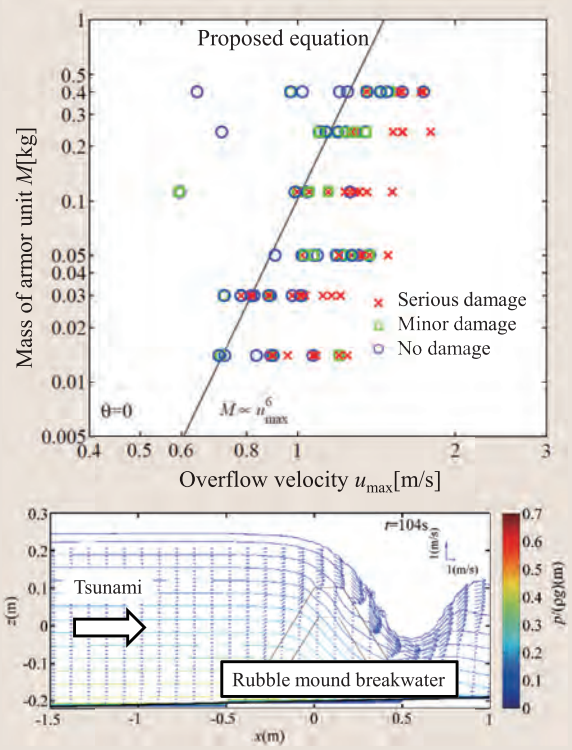


Fig. 2: Stability assessment of rubble mound breakwater

When the tsunami overflows a breakwater, a hydrodynamic load was applied to armor units of the breakwater. In the case that the hydrodynamic load is larger than the drag force of armor units, the armor units are drifted by the tsunami flow. The hydrodynamic load depends on the overflow velocity and the drag force depends on the mass of the armor unit. By carrying out model-scale experiments, we clarified the relationship between the mass of armor units and the overflow velocity in the stability condition (upper figure). The tsunami overflow was able to be numerically simulated well (lower figure).

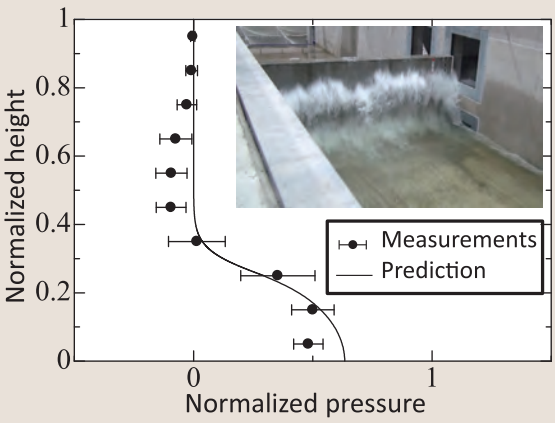


Fig. 3: Evaluation of tsunami impact pressure

An evaluation method of vertical profiles of tsunami impact pressure, which occur just after a tsunami tip impacts a structure, was proposed.

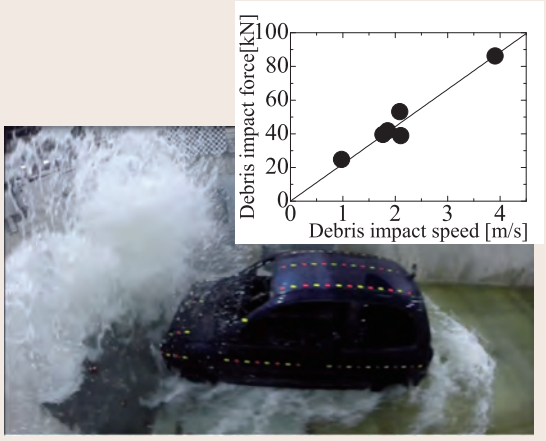


Fig. 4: Evaluation of tsunami-debris impact force

The graph shows the relationship between the debris (a real car) impact speed and force. The car was drifted in the tsunami bore. The graph shows that, in the velocity regime of tsunami inundation flow, the debris impact force linearly increases with the impact speed.

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

Assessment for the Effects of Natural Hazards on Nuclear Facilities

Background and Objective

The generation of nuclear power has declined substantially since the Great East Japan Earthquake of 2011, and this has resulted in the lack of stable electricity supply. We need to assess the magnitude and frequency of large-scale natural external phenomena including earthquakes, tsunamis, and volcanic eruptions. We need to understand their mechanism, so that we can implement mitigation measures to the facility and operation of nuclear power plants. This subject develops hazard assessment methods on natural external events as a part of the research program at NRRC aimed at safety improvement and development of PRA.

Main results

1 Application of seismic interferometry to an exploration of subsurface structure by using microtremors

Rayleigh-wave group velocities using synthesized Green's functions from seismic interferometry are applied to estimate deep subsurface geological structures. We carried out continuous measurements of microtremors at Ohshima peninsula (OSM) and Otomi peninsula (OTM) in the Wakasa bay region. Using more than 80 days' worth of data, dispersive waveforms in the cross correlations were identified as a Green's function from OTM (source) to OSM (receiver) based on seismic interferometry. By identifying deep subsurface structures at OSM and OTM based on an inversion of phase velocity from both methods, the depth of S wave velocity of approx. 3.5 km/s, considered as a top of seismogenic layer, was determined to be 3.8 - 4.0 km at OSM and 4.4 - 4.6 km at OTM (N14020).

2 Utilization of organic matter as the marker of tsunami deposit

Chemical (C/N) and isotopic ($d^{13}C$) analyses were used to determine the origin of organic matter in the 2011 Tohoku-oki tsunami deposits collected from 19 coastal areas. We found that these parameters can be useful markers to distinguish marine organic matter from freshwater; as we confirm that a marine signature is found in beach samples, while a freshwater signature is recognized in samples obtained from unaffected inland areas [1] (Fig. 2a). The method provides scientific criteria for the identification of tsunami deposit, and contributes to estimating the magnitude of pre-historic tsunamis and the distribution of their deposits (Fig. 2b).

3 Development of numerical analysis of volcanic ash dispersion coupled with the effect of meteorological condition

Numerical code for volcanic ash dispersion and ash-fall, Fall3D, is coupled with our weather forecasting and analysis system, NuWFAS. The method is capable of calculating temporal variation of particle concentration and accumulation of volcanic ash-fall, crucial to the hazard assessment of utility facilities. Dispersion of volcanic ash at the 2011 Kirishima volcano eruption is satisfactorily reproduced by our method (Fig. 3). Iterative improvements on the accuracy of defining boundary conditions, including meteorology and height of volcanic ash-cloud, are conducted to be applied to the hazard assessment of nuclear facilities (N14004).

[1] Ito et al., The Origin of Organic Matter in the 2011 Tohoku-oki Tsunami Deposit Determined by Chemical and Isotopic Signatures, AOGS 2014, Sapporo (2014).

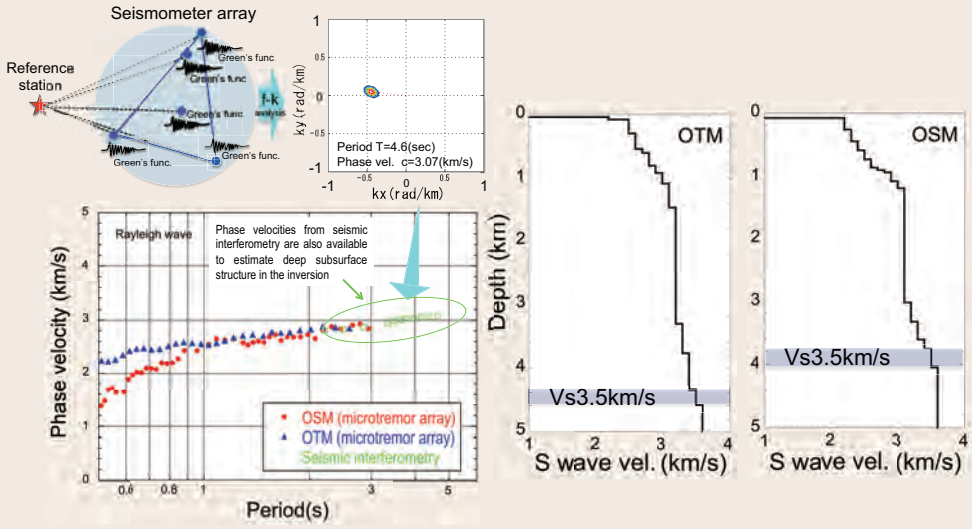


Fig. 1: Phase velocity inversion using synthesized Green's functions from seismic interferometry to estimate a deep subsurface geologic structure

We propose a method to estimate phase velocities by the f-k spectral analysis using the synthesized Green's functions with a common observation station. It is suggested that the deep subsurface structure of the shallow sea region between two peninsulas is continuous structure from OSM to OTM and that Love- and Rayleigh-wave group velocities using synthesized Green's functions from seismic interferometry can be used to validate identified deep subsurface structures.

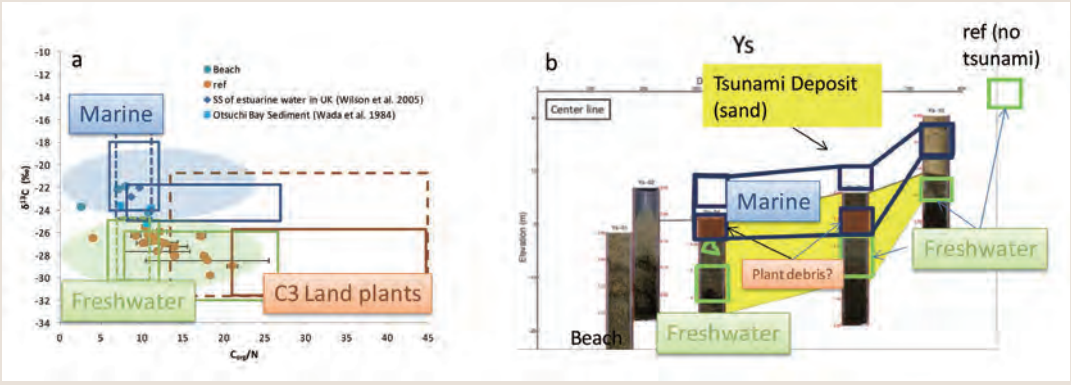


Fig. 2: Comparison of carbon isotope and C/N ratios between beach or estuary deposits, humic soil and tsunami deposits, and estimation of depositional environment of the sediments in the coastal region by organic marker

Chemical (C/N) and isotopic ($d^{13}C$) parameters are found to be useful markers to distinguish marine organic matter from a freshwater environment. We confirm that a marine signature is found in beach samples, while a freshwater signature is recognized in samples obtained from unaffected inland areas (Fig. 2a). Tsunami deposit is distinguished from river sediment by identifying its marine signature (Fig. 2b).

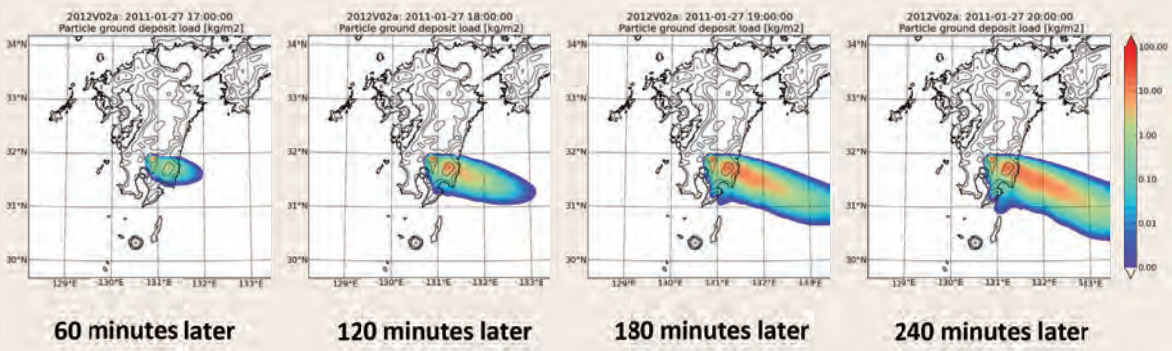


Fig. 3: Dispersion of volcanic ash-fall (Kirishima volcano 2011 eruption)

The calculated hourly dispersion of volcanic ash is displayed. The distribution expands southward due to the northerly wind on the day of eruption, which agrees well with observation. The method is capable of calculating the temporal variation of ash-fall accumulation and particle concentration at the given location. The method is therefore useful for the assessment of wide-ranging effects on utility facilities including mass load, intrusion and blockage of emergency generators and loss of external power.

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

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

Background and Objective

The radiation exposure to the public from environmental contamination caused by nuclear accidents and to workers in nuclear facilities is characterized as prolonged low-dose-rate exposure. Epidemiological research studies of residents in high background radiation areas suggest the existence of a dose-rate effect with no increase in radiation risks at a low-dose-rate. Understanding biological mechanisms of the dose-rate effect are needed to relieve public concern towards radiation exposure, and to establish scientific and reasonable protection systems. It is also useful to review the system of radiation protection that targets radiation use in general.

This project aims to reflect the dose-rate effect in radiation protection systems by elucidating its biological mechanisms through experimental studies, and to clarify the issues in risk assessment and radiation protection, which were revealed by the Fukushima Daiichi nuclear power plant accident, to support the resolution.

Main results

1 Construction and verification of a mechanistic model of dose-rate effects

It is known that cancers are caused by accumulation of genetic lesions in a group of tissue stem cells*1 (stem cell pool). In the case of high dose-rate radiation exposure, all cells in the stem cell pool are damaged simultaneously by radiation and most of them are lost by cell death. To keep tissue mass constant, the stem cell pool has to be replenished by damaged surrogate cells. This would result in accumulation of damaged stem cells (Fig. 1, right). In contrast, at a low-dose-rate, a limited number of stem cells in the pool are damaged at a time. Therefore, we hypothesized a dose-rate dependent mechanism that damaged cells may be eliminated by the turnover of stem cells or in competition with undamaged stem cells at a low-dose-rate (Fig. 1, left).

In order to verify this hypothesis, we evaluated whether stem cell pool affected by stem cell replenishment after the same cumulative dose by different dose-rate using genetic transgenic mice, in which loss of the stem cell pool can be detected by color. After 1 Gy irradiation, stem cell replenishment could be observed, however, it could not be detected by a low-dose-rate (Fig. 2). This result indicated that the stem cell pool could be affected by independent mechanisms under different dose rate conditions.

2 Identification of important solutions by surveying the reports related to the Fukushima Daiichi Nuclear Power Plant accident

Regarding radiation exposure of the members of the public and radiation workers due to the release of radioactive substances from the Fukushima Daiichi Nuclear Power Plant accident, several issues on dose/risk estimation, and on radiation protection were enumerated by domestic and international professional bodies. In order to apply those lessons learned and experiences for the development of protective actions and for the improvement of the system of radiation protection in the future, identification of main solutions is necessary. For this, by surveying dose and risk estimation reports*2 published by the professional bodies, uncertainty factors have been categorized and assessed from the viewpoint of their characteristics such as the possibility of a substitute plan, etc., to identify the major requirements and corresponding solutions. Then, the relationship between those solutions and radiation protection issues were clarified. Consequently, it was found that the important solutions, which means common and noteworthy challenges for both dose/risk estimation and radiation protection issues, were implementation of personal monitoring at the emergency exposure situation*3 for reduction of the uncertainty of dose estimation, and quantified assessment of low-dose radiation risks, which is the basis of adequacy judgement of risk evaluation and radiation protection standards (Fig. 3).

*1 Cells of origin which maintain the tissues with small number and can produce functional cells throughout life.
*2 Reports published by the World Health Organization (WHO), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological protection (ICRP), and the Japan Health Physics Society were selected.
*3 A situation requiring urgent action to avoid or reduce the risk of radiation exposure.

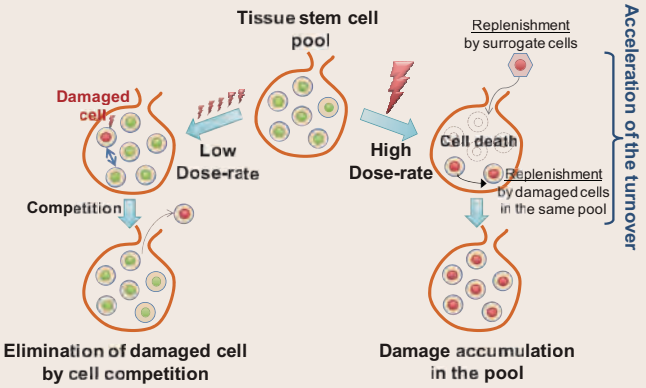


Fig. 1: A mechanistic model of dose-rate effect and stem cell replenishment

The stem cell pool was maintained by replenishment of surrogate cells at a high dose-rate, then damage accumulated in the pool (right). In contrast, stem cells were maintained by turnover or cell competition, which can eliminate damaged cells (left). However, an experimental turning point of the dose-rate effect is still unknown. Using transgenic mice, stem cell replenishment can be detected as the loss of blue-stained tissue components, named crypts.

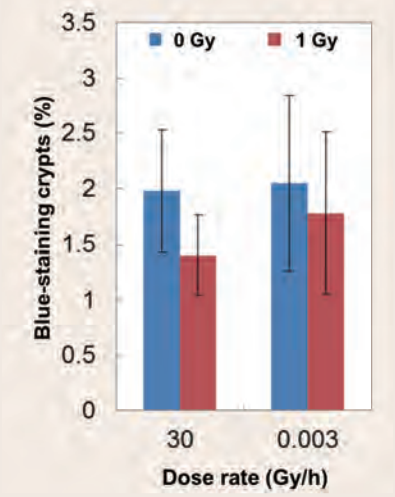


Fig. 2: Dose-rate effect of stem cell replenishment

Percentage of blue-staining crypts after 1 Gy (red bars) irradiation by high dose-rate (30 Gy/h, left) or low dose-rate (3 mGy/h, right), compared to unirradiated background levels (blue bars). Statistically significant replenishment was observed only at high dose-rate radiation exposure (p=0.04).

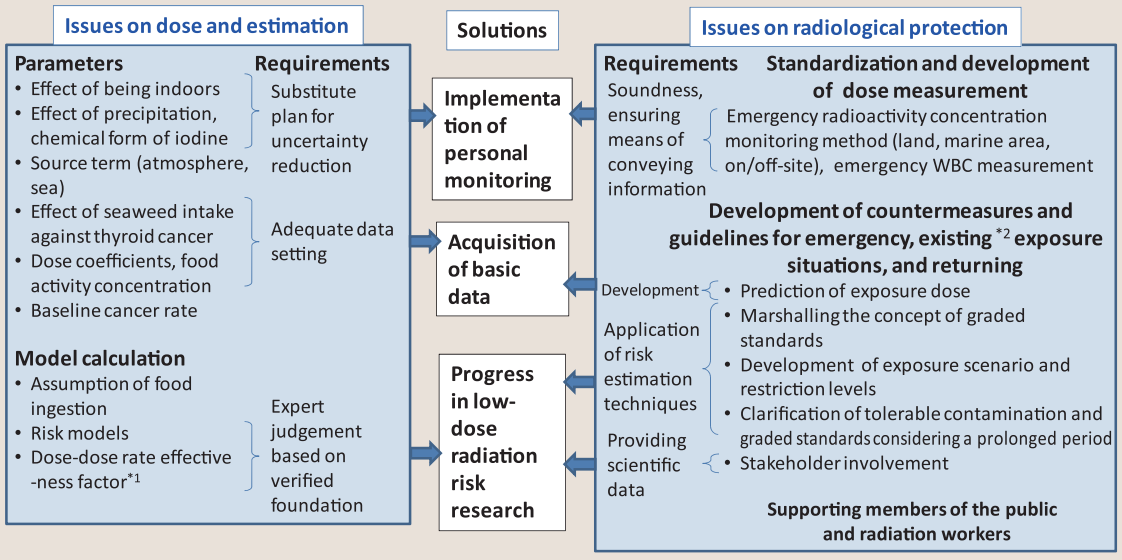


Fig. 3: Important issues and solutions on dose/risk estimation and on radiation protection

Uncertainties in the dose and risk estimation relate to the parameter values and the models performed in the calculation. It was found that those two issues were important since the former includes external doses during and after the nuclear power plant accident, which is difficult to improve the accuracy of afterwards; the latter includes dose-dose rate effectiveness factor, which requires the adequacy of expert judgment (Fig. 3, left). Furthermore issues on radiation protection, which were identified and enumerated by the professional bodies from their own viewpoints, were comprehensively reviewed (Fig. 3, right). In order to solve the issues on uncertainty related to dose and risk estimation, and on radiation protection, it was clarified that implementation of personal monitoring and progress in low dose risk estimation researches are especially important (Fig. 3, center).

*1: A reduction factor to estimate radiation risk at a low-dose and a low-dose-rate exposure.
*2: A situation in which there is an existing radioactive source prevalent, such as exposure over a prolonged period following a nuclear accident.

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

Development and Systematization of Long-term Safety Assessment Technologies for Radioactive Waste Disposal

Background and Objective

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 requires 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 and the systemization of site selection.

In this project, R&D of LLW disposal aims to develop methods of gas migration through engineered barriers and to estimate alteration of bedrock by concrete covering in order to build a reliable technology. R&D of HLW disposal aims to confirm the applicability of the methodology for the investigation and assessment of properties of geological environment utilized in site investigation for geological disposal.

Main results

1 Establishment of an evaluation method of gas migration through compacted bentonite

Compacted bentonite and Ca-bentonite mixture, which will be used as engineered barriers for inhibiting migration of radioactive nuclides, are so fine that the hydrogen gas, which is generated mainly by the chemical interaction between aluminum and the alkaline component of cement, cannot penetrate the barriers easily. Thus gas migration tests together with their numerical simulation were conducted using CRIEPI's original code 'GasDeform2D' based on the model of two phase flow through deformable porous media. As a result, it was revealed that the test results, such as stress change and volume of discharged gas, can be reproduced with precision by the numerical simulation (Fig. 1) (N23).

2 Analytical estimation on weathering and alkaline alteration of bedrock wall

Block shape samples of neogene period rock with and without concrete covering were collected from the wall of gallery five years from excavation, then the states of weathering and alkaline alteration were analyzed. Rock without concrete covering showed an oxidization effect with browning to a depth of as much as 1.5 to 3 cm at the surface area. Rock sprayed with concrete showed a rise in Ca concentration and pH, to approximately pH10, up to 20 cm depth beneath the concrete. The amorphous component of rock has reacted with alkaline leachate from concrete to form calcium silicate phase as secondary product, then the pore of rock was filled with the product (Fig. 2).

3 Survey methods considering the reduction of uncertainty in obtaining properties of the deep geological environment to conduct site investigation for geological disposal*1

The Yokosuka Demonstration and Validation project using the Yokosuka CRIEPI test site was conducted to confirm the applicability of the basic methodology of the investigation and assessment regarding properties of geological environment to conduct site investigation for geological disposal. The applicability of important elemental technologies such as a borehole survey and a geophysical prospecting for obtaining information concerning the deep geological environment from the surface has been confirmed through this project [1]. For the purpose of reducing the uncertainty in obtaining the properties of the geological environment, a series of additional surveys (a new borehole survey and crosshole tests between the new and the existing boreholes) was conducted. The contribution and applicability of these additional surveys to improving the degree of understanding of the geological environment was confirmed based on the results of these surveys (Fig. 3).

*1 This research was conducted as a cooperative research project with the Nuclear Waste Management Organization of Japan (NUMO).

[1] H. Kondo et al., J. Geol, Soc, Japan, Vol. 120, No. 12, 447-471, 2014.

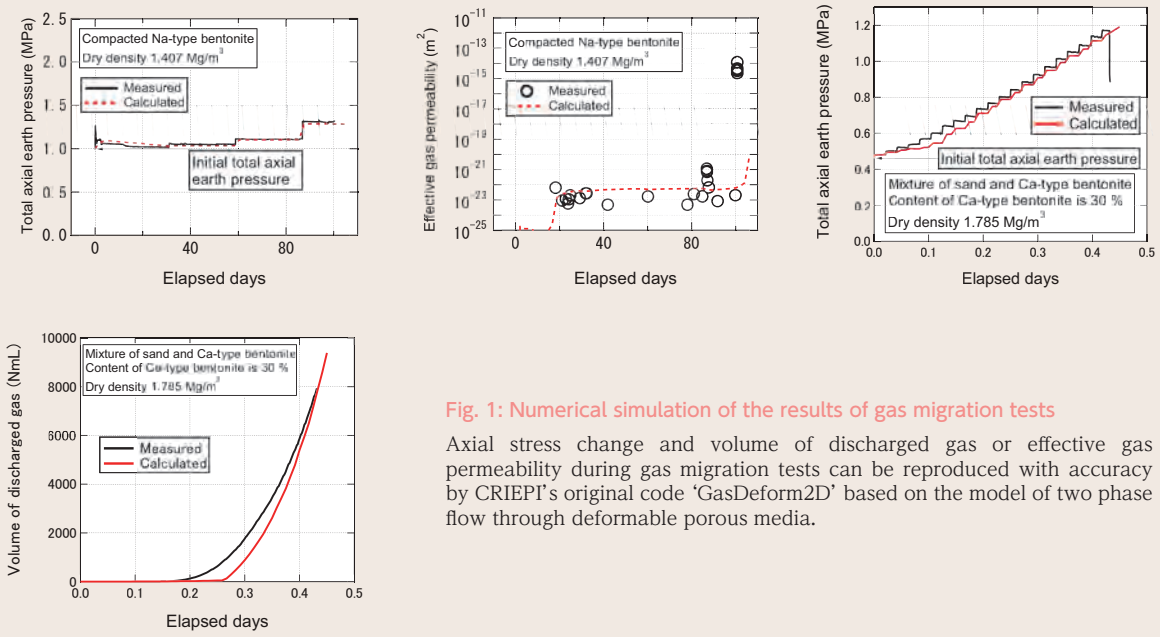


Fig. 1: Numerical simulation of the results of gas migration tests

Axial stress change and volume of discharged gas or effective gas permeability during gas migration tests can be reproduced with accuracy by CRIEPI's original code 'GasDeform2D' based on the model of two phase flow through deformable porous media.

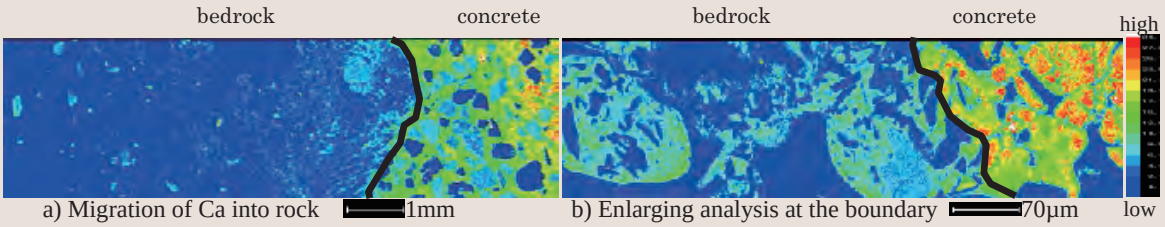


Fig. 2: Ca distribution in bedrock beneath concrete

Ca and OH ion leached from concrete have migrated into the pore of rock, then reacted to form calcium silicate phase at the surface of volcanic glass and clay grain with obtaining a compaction effect in the rock (yellow to green colored contour area in the figures). The compaction effect with dilution effect from ground water derives a depressing effect on the migration of alkali ions.

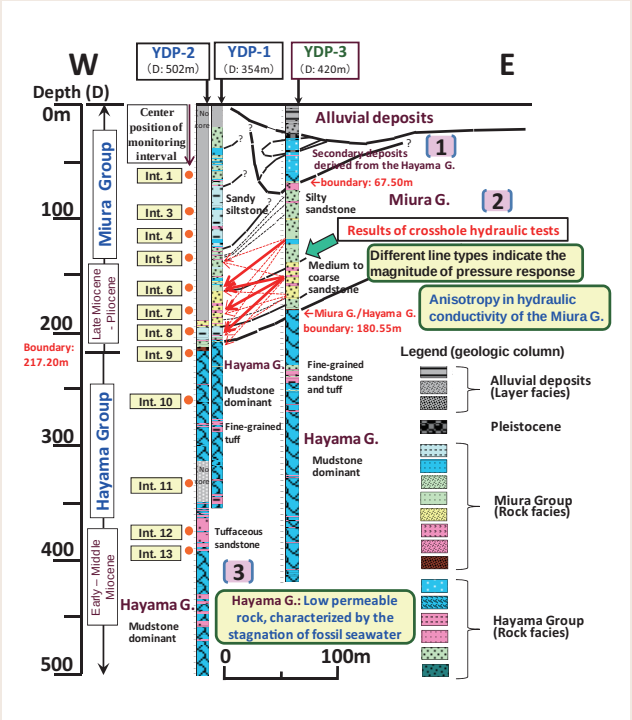


Fig. 3: Outline of the results of borehole surveys and crosshole tests along the cross-section passing through the boreholes of YDP-3 and YDP-2 in the Yokosuka CRIEPI area

A series of additional surveys (a new borehole survey at YDP-3 and crosshole tests between boreholes of YDP-3 and YDP-2) was conducted in the Yokosuka Demonstration and Validation project using the Yokosuka CRIEPI test site. Through these surveys, 1) the distribution and characteristics of the base rock geology under the alluvial deposits, 2) the lateral continuity in geology and the anisotropy in hydraulic conductivity of the Miura Group, 3) the low permeable rock properties of the Hayama Group having stagnant fossil seawater, were revealed with higher reliability than the previous stage surveys (the borehole surveys of YDP-1 and 2). The contribution and applicability of these additional surveys to improving the degree of understanding of the geological environment was confirmed based on the results of these surveys.

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 fuels generated from nuclear power plants until they are reprocessed is necessary. Furthermore, it is important to prepare for an increase in storage amount and an extended storage period. Many dry interim storage facilities using metal casks exist in countries around the world, including Japan. It is also necessary to evaluate the safety of post-storage transport, taking into account aging of the components during the storage period. The early realization of interim storage facilities using concrete casks is demanded in Japan from an economical point of view.

In this project, we aim to develop an evaluation method for confinement of metal casks which takes aging into account. For the practical use of concrete cask technology, we aim to improve an evaluation technology for stress corrosion cracking (SCC) and an investigation method for welding of canisters*1. The objectives of this subject are to make use of these results for the safety of interim storage of spent nuclear fuel.

Main results

1 Performance validation of measurement device for sea salt in air by insitu measurement near the seashore

Because it is necessary to know the volume of sea salt in air at a storage site in order to evaluate the SCC of a canister, we developed a simple device to measure sea salt in air continuously and automatically over a long period. To validate the performance of our device, we compared the measurement results of our device with the results obtained simultaneously by another device based on a filter pack method at a marine exposure test field at CRIEPI's Yokosuka site. The device based on the filter pack method is one of the standard devices used. The comparison results show that the two devices have almost identical performance when measuring the volume of sea salt in air (Fig. 1).

2 Evaluation of relationship between sea salt in air and salt amount deposited on the canister surface

In our past studies, we measured the salt deposition amount in a laboratory and at an exposure test field located in Choshi at a distance of 4 km from the seashore. To add data of different environment conditions, we measured the salt deposition amount in a marine exposure test field carried out at CRIEPI's Yokosuka. In the test, we measured salt amount deposited on the test piece placed in the vertical wind tunnel in which outside air is introduced by a blower as well as in the horizontal wind tunnel. The chorine amounts deposited on the test piece in the vertical wind tunnel were less than 10 mg/m^2 within the test duration (Max: 6900 hours)(Fig. 2) (N14019). This value is similar to the results obtained at Choshi and much smaller than the values of salt deposition on the bridge and electrical equipment near the seashore and threshold value of SCC.

3 Development of a device for remote measurement of salt deposited on canisters

It is important to ensure the integrity of canisters by measuring the salt deposited on the canister surface and evaluating the occurrence of SCC. Remote measurement is an important issue as the radiation dose near the canister surface is very high and the space between the canister and concrete body is narrow. In this study, we clarified that the measurement method by laser-induced break down spectroscopy (LIBS)*2 is applicable and developed a compact device comprised of optics for LIBS and a drive unit for vertical movement in the space between the canister and a concrete body. We confirmed the measurement accuracy of our device using a miniature model simulating the narrow space between a canister and a concrete body. We moved the compact device up and down in the model and measured the salt deposits on the test piece placed on the side wall of the model (Fig. 3). The distance from the laser device to the measurement points was around 5 m and the space between the walls was 50 mm. As a result, the value obtained by LIBS (value calculated by intensity of chlorine fluorescence normalized by oxygen fluorescence) is in good agreement with the value obtained by ion chromatography within the measurement range of chlorine density between 0 to 100 mg/m^2 (Fig. 4). These results show that it is possible to measure the chlorine amount deposited on canisters stored in the concrete cask using our device for remote measurement which adopts LIBS technology (H14004).

*1 A cylindrical container made of stainless steel which contains spent nuclear fuel and is placed in a concrete cask.
*2 When the laser pulse irradiates to a target, the spectra of plasma emission is obtained. By analyzing the emission spectra, contained elements concentration on the target is evaluated.

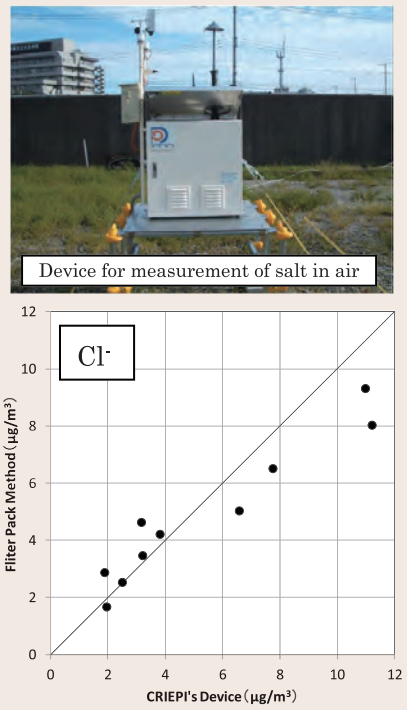


Fig. 1: Comparison of chlorine in air between the measurement values obtained by our device and existing device (Filter pack method)

To clarify the performance of our measurement device, we compared the measurement values obtained by our device with the values obtained by an existing standard device based on the filter method. As a result, it was confirmed that the performance of our device is equivalent to that of the existing device.

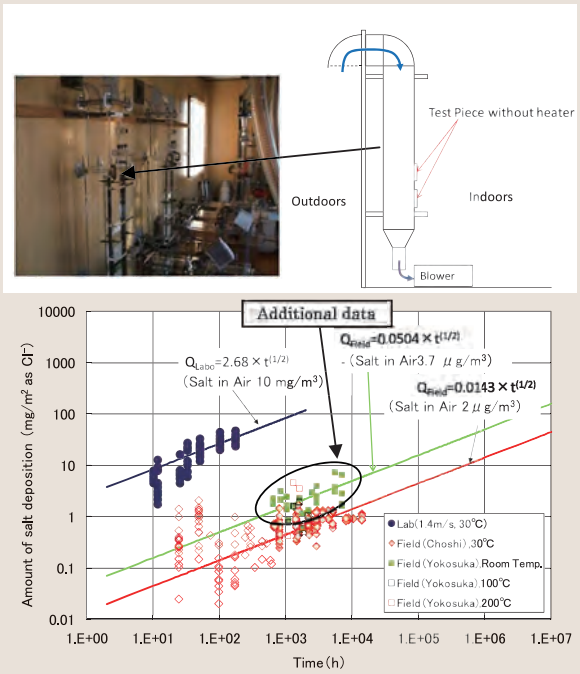


Fig. 2: Relationship between the amount of salt deposition and time in the tests using vertical wind tunnel

We measured the amount of salt deposition attached to the test piece using a vertical simplified wind tunnel simulating the flow area of a concrete cask. Outside air was introduced to the wind tunnel using a blower. We obtained additional data regarding salt deposition with different environment conditions from the existing data. The relationship between the amount of salt deposition and time obtained in additional tests are similar to the existing data. The dispersion of data in additional tests is relatively small.

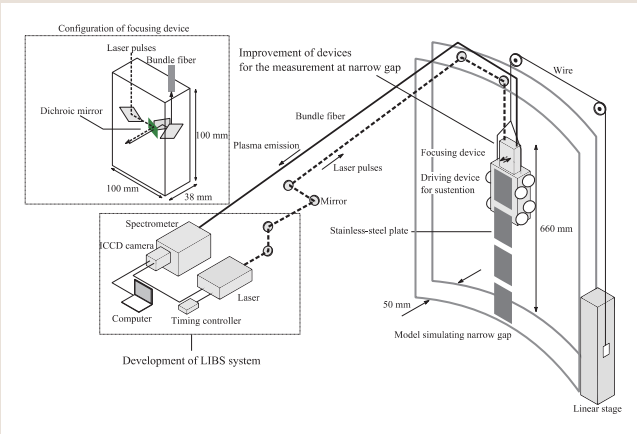


Fig. 3: Outline of miniature model simulating the narrow space between a canister and a concrete body

We developed an LIBS device for measurement of salt deposit on canisters and modified a compact device comprised of optics for LIBS and a drive unit for vertical movement in the narrow space. In the tests, using a miniature model simulating the narrow space between a canister and a concrete body with curvature, we measured the salt deposit on test pieces made of stainless steel placed on the side wall of the model. Artificial sea water was sprayed on the test pieces before measurement. One of the test parameters was the salt deposit on the test pieces.

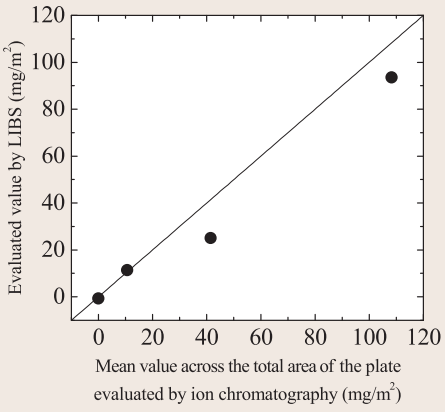


Fig. 4: Validation of measurement method based on the LIBS technology

We compared the results of the chlorine amount deposited on the test piece obtained by LIBS with the results obtained by ion chromatography. It is clear that each result is in good agreement. The applicability of the measurement method using LIBS was confirmed.

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

Development of Prediction Methods for Weather/Climate Impact on Electric Power Facilities

Background and Objective

The occurrence of natural disasters, associated with large-scale typhoons, rapid-developing low pressure systems, localized heavy rainfall and snowfall, and gusty winds due to tornados and downbursts, tends to be increasing. Recently, we have experienced extreme recorded events, raising concern regarding the influence of global warming. In this project, prediction methods of extreme meteorological disasters, methods for utilization of predicted products, and meteorological and oceanographic hazard evaluation methods are developed as techniques for supporting advance prevention of disasters in routine operations and for rapid restoration in the wake of disasters. The evaluation of the impact of tornadoes on nuclear power plants is another major topic. Results in this project are expected to contribute to improving the reliability of electric power facilities and the stability of power supply.

Main results

1 Development of a short-range precipitation prediction system

In this system, two types of products are routinely predicted (Fig. 1). One is a product of 3-km prediction up to 9-hours in advance to cover the entire country. The other is a product of 2-km prediction up to 2-3 hours in advance to cover a particular region (e.g. Kanto area). The higher-resolution prediction is performed in a rapid update cycle (every 10-20 minutes). Both predictions utilize real-time weather radar data from the Japan Meteorological Agency (JMA) and Ministry of Land and Infrastructure, Transport, and Tourism, and surface observation data (e.g. AMeDAS and wind profiler, etc.) is processed automatically. Data assimilation of this data into our numerical weather forecasting and analysis system (NuWFAS) improved the accuracy of a short-range precipitation prediction.

2 Suggestion of a method to utilize JMA weekly ensemble forecasts*1

In order to conduct higher-resolution rainfall forecast based on weekly ensemble forecast data provided by JMA, the two techniques described below were developed. One is a method for 2-day prediction of hourly precipitation, which is based on a dynamical ensemble approach using NuWFAS, and the horizontal resolution is about 5-15 km (V14013). The other is a method for one-week prediction of daily precipitation using a pattern recognition technology (Fig. 2). Since both methods can estimate the range of fluctuations and time-lags for each weather variable, they can support end-users to make decisions in accordance with the reliability of the prediction.

3 Techniques for assessing the impact of tornadoes on nuclear power plants

A method to evaluate tornado parameters*2 is suggested for assessing the regionalization in terms of the frequency of favorable meteorological conditions which lead to the occurrence of tornadoes with the largest scale (F3*3) recorded in Japan or with larger scales. This method adopts a high-resolution and long-term reanalysis dataset called CRIEPI-RCM-Era2, and its applicability is verified from analyses of F3-F5 tornadoes which have occurred in Japan and the United States. A method for hazard assessment of tornado wind velocity, which is called TOWLA, is also developed, accounting for the likelihood that the majority of tornadoes have occurred in coastal areas of Japan. The usability of TONBOS, which is a tool for evaluating the velocity and the trajectory of tornado missiles, is also improved.

Concerning a countermeasure with high-strength wire mesh against the penetration of tornado missiles, the applicability of our method to evaluate the absorbed energy is examined through free drop tests using a heavy weight [1] (N14009). In addition, the effects of attaching additional wire mesh on the main wire mesh are verified to demonstrate the capability of resisting the penetration (N14018). Results and findings obtained in our research are significantly useful for the establishment of relevant guidelines by the Japan Society of Maintenology and the relevant standard by the Japan Society of Mechanical Engineers.

*1 An ensemble forecast is composed of forecast members, each of which is a forecast consisting of initial and boundary conditions with artificial perturbations. In this summary, the term "forecast" refers to public broadcasts by organizations such as JMA. Non-public information is, referred to as a "prediction".

*2 Tornado parameters indicate atmospheric instability, wind shear, and other elements. Those parameters are used in issuing a warning or in nowcasting by JMA. In our method, tornado parameters such as convective available potential energy (CAPE), storm-relative helicity (SReH), and the energy helicity index (EHI; EHI=CAPE×SReH/160,000) are used.

*3 The Fujita scale is an index of tornado intensity estimated from the degree of structural damage. This is used to estimate the wind velocity. For example, the range of the velocity for F2 tornadoes is 50-69 meters per second (averaged in 7 seconds), and the range for F3 tornadoes is 70-92 meters per second (averaged in 5 seconds).

[1] K. Namba et al., J. Structural Engineering, Vol.61A, 958-969, 2015.

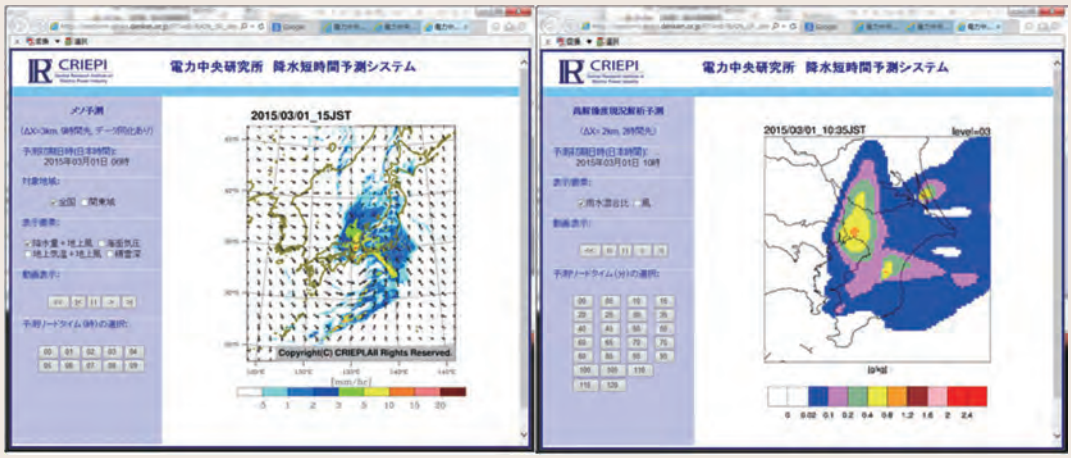


Fig. 1: Graphical user interface to browse products from our short-range precipitation prediction system (left: a full domain with 3-km horizontal resolution, right: a regional domain with 2-km horizontal resolution)

Our prediction system is developed for more quantitative precipitation predicted up to several hours in advance. Observed information such as radar data is incorporated into the result of 33-hour prediction from NuWFAS. In predictions covering the entire country, the use of three-dimensional variational data assimilation system (WRFDA) improves the accuracy of prediction up to 9 hours. In regional predictions, the rapid update cycle of a higher-resolution prediction is achieved with the four-dimensional variational radar data assimilation system (VDRAS), so that the quantitative prediction is improved even for a rapid-developing storm in a local area. Our system can be easily customized in terms of the duration of prediction, and the domain size according to the computational performance.

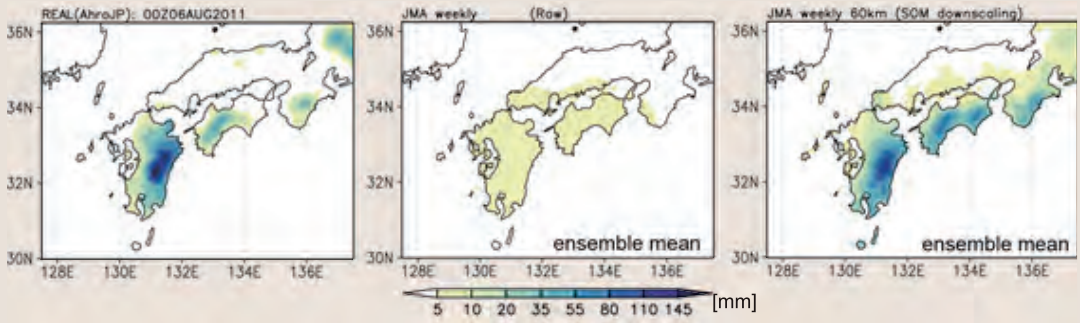


Fig. 2: Example of 1-week prediction of daily precipitation based on the developed method using the pattern recognition method (left: observation, middle: JMA ensemble forecast, right: our method)

A statistical pattern recognition technique called a self-organizing map is applied to reanalysis data and rainfall data. A few hundred weather patterns are identified, indicating the relationship between the spatial distribution of meteorological elements (e.g. the wind speed and the direction at 850 hPa height) with a lower-resolution and the rainfall distribution with a higher-resolution. This method enables us to predict immediately heavy rainfall area up to around 1-week in advance from a low-resolution JMA weekly ensemble forecast and its associated weather pattern, even if the original JMA forecast cannot predict heavy rainfall area.

Comparison of values of absorbed energy estimated with experimental values

Resisting a heavy weight simulating the impact of a pipe in a squared shape

Fig. 3: Examples of results of our study on the countermeasure with high-strength wire mesh against tornado missiles(left: observation, middle: JMA ensemble forecast, right: our method)

Our proposed method to evaluate the absorbed energy by the wire mesh is validated by comparison between estimated values and experimental values obtained from free drop tests (left panel). Moreover, it was confirmed that the performance of the wire mesh system is improved in terms of the catchment ability by attaching additional wire mesh. No local penetration of the falling heavy weight was found (right panel).

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

Establishment of Protective Measure Technologies against Damages to 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 the following damages to overhead transmission facilities: the partial collapse of transmission towers resulting from overload of heavily accreted snow, the short circuiting of transmission lines caused by galloping*1, and the failure of electrical insulators, or flashover due to heavily accreted snow containing sea salt. After the occurrence of snow-related damage, CRIEPI began a ten-year research project from FY 2007 to 2016 on damage to overhead transmission facilities caused by severe snowstorms. This project is conducted in cooperation with electric power companies.

In the first phase (from FY 2007 to 2011) of this project, field observations were mainly conducted in order to elucidate the physical processes of snow-related damage and to examine current countermeasures. The second phase of the project commenced in FY 2012 to propose effective countermeasures against the snow-related damage using practical analysis and prediction methods. Applicability of the research results to distribution facilities is also investigated.

Main results

1 Continuous operation of field observation and consolidated data management systems

On the Kushiro Test Line constructed in FY2013, we obtained some samples of noticeable wet-snow accretion with strong wind, which clearly suggest conditions that the effect of the snow resistance ring, a representative anti-icing device, tends to appear and there is an impact from the heat generated by an electric current (Fig. 1). Furthermore, field observation data related to meteorological conditions of snow-related damage and the effect of countermeasures have been obtained in eight other sites in Japan. A data management system to store practical examples of snow-related damage and their meteorological conditions has been continuously operated, and 663 practical examples*2 have been newly added to the data base. This data is used in the elucidation of meteorological conditions of snow-related damage, examination of its prediction methods, and evaluation of effectiveness of measures against it.

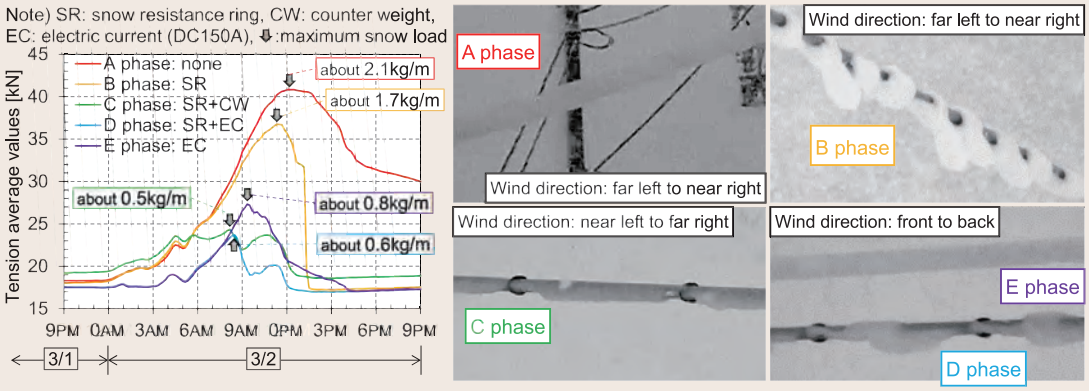
2 Elucidation of snow-related damage and development of its prediction methods

A simple snow accretion model, which we have developed for estimation of snow load on transmission towers, has been examined by using observation data at meteorological offices. New hazard maps, which can be used for evaluation of the possibility of galloping occurrence, have also been produced based on a numerical simulation weather prediction model and analysis of meteorological statistics (Fig. 2). These results can be utilized for establishment of effective and reasonable countermeasures for snow-related damage.

3 Development of a model for snow accretion to electric wires, and its melting and shedding

A snow accretion simulation code developed by CRIEPI, named SNOVAL (Ver.2), has been extended to improve its accuracy. A model of snow accretion to electric wires and its melting is newly incorporated in SNOVAL (Ver.2). This model enables us not only to calculate the liquid water content of the snow deposit by taking into account the melting process due to heat exchanges with the air, but also to give the density of snow deposit and snow accretion factor evaluated based on the liquid water content. Adhesive force between the snow deposit and electric wire is also estimated based on the liquid water content. Furthermore, SNOVAL (Ver.2) is improved to incorporate a snow shedding model, in which the time of snow shedding is evaluated based on the balance between the adhesive force and gravitational, aerodynamic forces exerted on the snow deposit, or on the balance of moments related to these forces (Fig. 3). The extended version, SNOVAL (Ver.3), is thus able to reproduce the process from the start of snow accretion until snow shedding. The findings obtained from the analysis with SNOVAL (Ver.3) are utilized to improve the accuracy in the simple method for the estimation of accreted snow mass described in 2 and to predict the snow deposit shape necessary for galloping analysis.

*1 Self-excited oscillation of conductors due to wind and accreted snow or ice. If the amplitude becomes large or the oscillation continues, the phenomenon causes short circuiting or facility failure through fatigue.
*2 Practical examples of short circuiting and damage to electric facility such as supports and conductors due to icing.



(a) Changes in conductor tension average values at 10-minute intervals

(b) 3/2 at 10AM, snow accretion 30-40M from towers (span length 300M)

Fig. 1: Examples of Snow Accretion Measurement on the Kushiro Test Line Single Conductor Lines (2015/3/1-2)

Conductor tension increased with snow accretion in all phases, but the increase due to snow accretion was limited in lines with snow resistance rings compared to those without the rings, and even greater snow volume was limited in its accretion in the C phase where counterweights were also used (left figure). Also, on lines with the snow resistance rings, the rings divide the snow, causing it to slide off (right image). Furthermore, the melting of the snow due to the heat generated from the electric current and the snow slide from the wire surface clearly shows the effects of this rings compared to the phase without electric current.

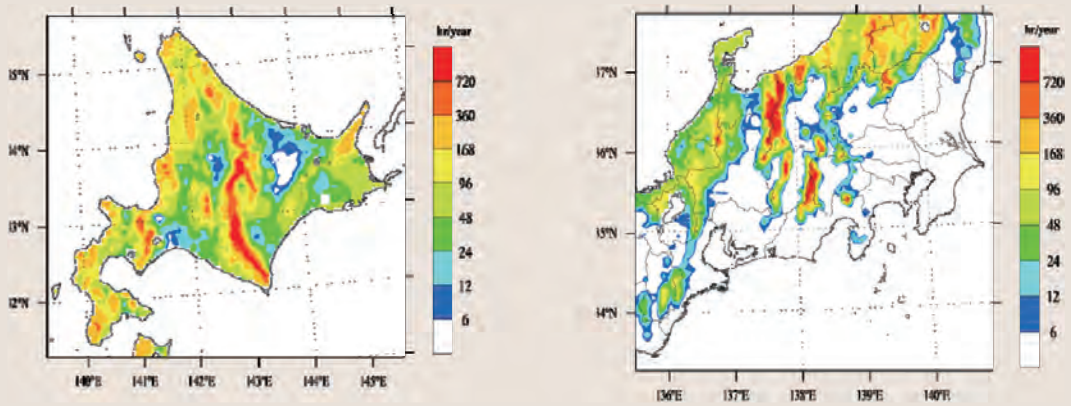
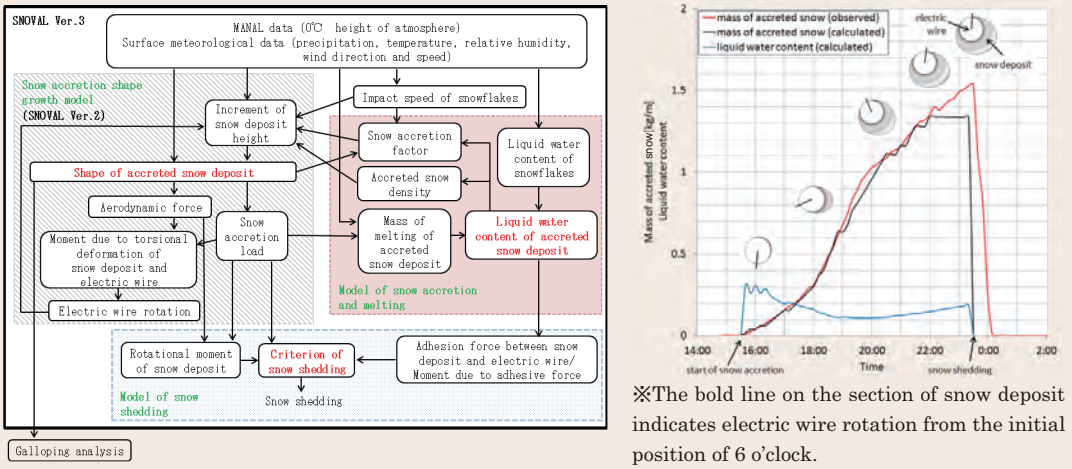


Fig. 2: Hazard maps for galloping occurrence

New hazard maps across Japan which show the frequency of weather conditions for galloping occurrence (frequency per year where snow accretion on transmission line occurs and the wind speed is beyond a certain threshold value) were made for each direction of transmission line by using the high-resolution long-term weather and climate database (CRIEPI-RCM-Era2), which was derived from a weather forecasting and analysis system (NuWFAS). The possibility of galloping occurrence in each area can be easily evaluated by using the maps, and can be used for extraction of locations where galloping tends to occur.



※The bold line on the section of snow deposit indicates electric wire rotation from the initial position of 6 o'clock.

Fig. 3: Framework of SNOVAL (Ver.3) and analytical results for a snow accretion event

SNOVAL (Ver.3) is an extended version based on SNOVAL (Ver.2: snow accretion shape growth model), and incorporates an input of meteorological data of surface and atmosphere, models for snow accretion, its melting and shedding, taking into account the melting process of snow deposit (left figure). All processes from the start of snow accretion and growth, until snow shedding are accurately reproduced with these models (right figure).

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, in the future, ICT (Information and Communication Technology) will be increasingly applied to power systems such as smart meters and the capacity of renewable energy sources such as wind power and solar power will increase. 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 their electro-magnetic immunity. We will then utilize these lightning protection guidelines for the rational lightning protection design of power systems.

Main results

1 Investigation of relationship between lightning strikes to extremely high structures and meteorological conditions

We have observed lightning strikes on Tokyo Skytree, the height of which is 634 m, to clarify lightning striking characteristics on extremely high structures such as UHV transmission lines*1. Approximately 40 events were successfully observed from 2012 to 2014. From this data, we have found that downward lightning to the tower and upward lightning from the tower generally occurs when the height of -10°C is higher than 5,500 m and lower than 5,500 m, respectively (Fig. 1). In addition to this, we have obtained statistical distributions of peak values of lightning currents and transferred charges of lightning flashes for both types of lightning (Fig. 2) (H14015).

2 Establishment of an immunity test method for IP equipment installed in power stations

Consideration of immunity against electromagnetic interference has become one of the important issues in installing ICT devices in power stations and substations. In this study, a model estimating packet loss rate in the IP transmission against burst noises was established based on experiments. The model estimates packet loss rate by considering duration and cycle of a burst noise*2, and elapsed time of IP packet transmission. Using the loss estimation model, a simple and effective immunity test scheme for IP devices to be installed in power stations and substations was proposed (Fig. 3) (H14012).

3 Enhancement of lightning database based on the recent data of lightning location systems

Collaborating with electric power companies in Japan, we have constructed an enhanced lightning database tracking up to the year 2013 based on the data of lightning location systems. From the database, we have clarified the annual variation of lightning occurrence, relationship between lightning occurrence and meteorological conditions, and correlations between the number of outages of transmission lines and that of lightning occurrence.

4 Potential for relaxation of the regulations on grounding of communication lines of power systems

Aiming at relaxation of the regulations on grounding of communication lines of power systems, we have investigated the possibility from three viewpoints; namely, lightning, mixture contact of AC circuits and electromagnetic induction, with full-scale experiments and computer simulations. As a result, we have found that the regulations on grounding resistance value and interval of grounding points can be relaxed.

*1 Collaborative research between CRIEPI, the University of Tokyo and Tobu Tower Skytree Co. Ltd.
*2 A train of repetitive impulsive noises characterized by number, duration and period of repetition of pulses.

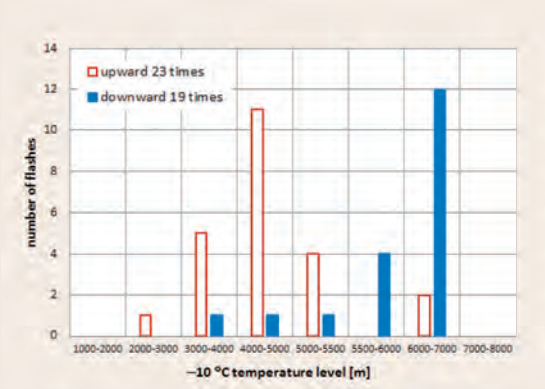


Fig. 1: Occurrence of upward and downward lightning flashes and height of -10℃ level upward lightning and downward lightning

It has been considered that lightning strikes on structures with heights of over 500 m is mostly upward (more than 90%). However, in the case of Tokyo Skytree, downward lightning flashes are often observed. Hence we have investigated the meteorological conditions when lightning to the tower occurs and have discovered that most of upward lightning flashes occur when the height of -10°C level is lower than 5,500 m.

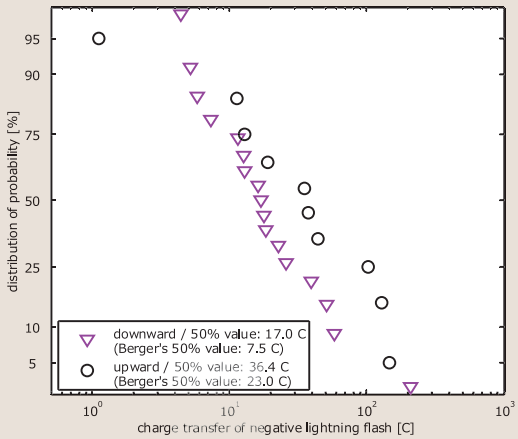
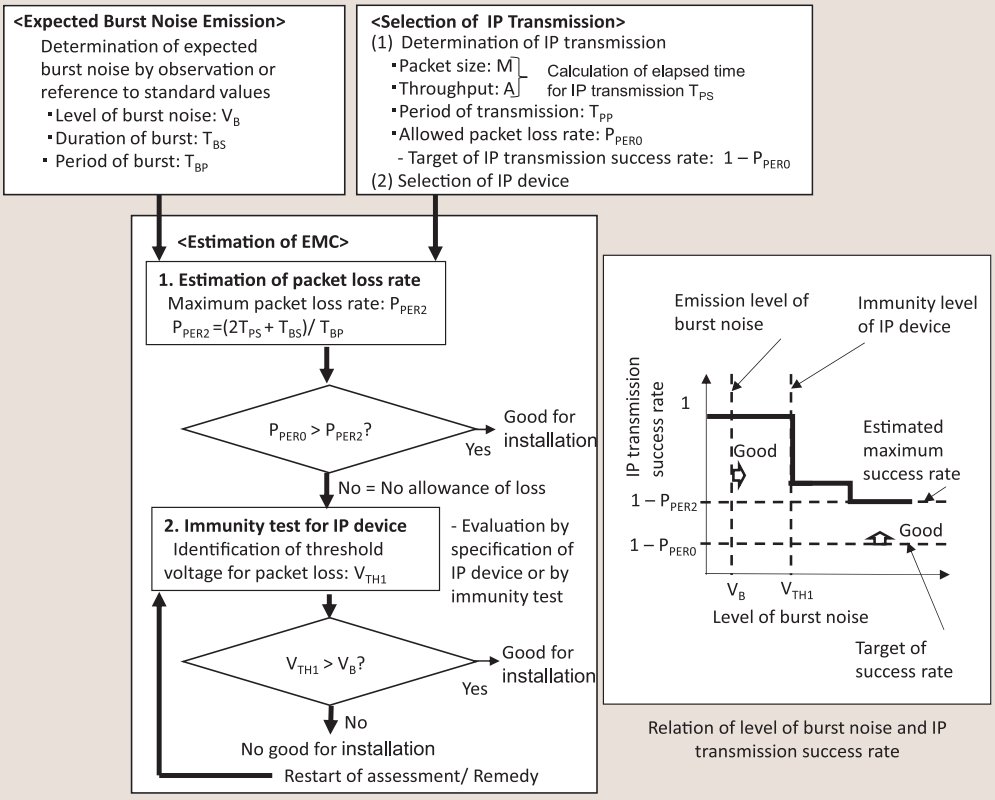


Fig. 2: Cumulative distributions of transferred charges of upward and downward lightning flashes

In regards to the lightning parameters such as peak current and transferred charge, the data observed in Switzerland by Berger is popular around the world. Present data observed at Tokyo Skytree is almost the same as that for the cumulative distribution of lightning currents, but the median value of transferred charges are 1.5 to 2.3 times larger than the values previously reported and the difference by regions is shown.



Relation of level of burst noise and IP transmission success rate

Fig. 3: Immunity test scheme for IP devices to be installed in power stations and substations

The IP transmission success rate rapidly changes at a level of applied burst noise, and converges to a value determined by cycle and duration of the burst noise and cycle of packet transmission. In the immunity test, the estimated maximum IP transmission success rate will be compared with its target value. If it is not satisfied, another investigation will be conducted, i.e. the threshold voltage emerging packet loss for the IP device will be compared with the noise level at the location.

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

Well-functioning Electricity Market and Network Neutralization

Background and Objective

In Japan, the government has presented an outline of new energy policy, while electricity system reform is well underway. In foreign countries, there has been a growing concern about keeping nuclear power plants after liberalization and the problems associated with an increase in renewable energy generation. It is important for Japan to ensure consistency between national energy policy and electricity system reform. This project conducts a detailed investigation of the issues in institutional design for the electricity system reform and, at the same time, evaluates the experiences in other countries regarding the issues relating to the national energy policy, such as nuclear power generation in a competitive environment and utilization of renewable energy generation, thereby contributing to an improvement of business environment after the reform.

Main results

1 Evaluation of financing methods for nuclear power generation in Europe after liberalization

We evaluated the financing methods for nuclear power plants under competitive environment in Europe after liberalization (Table 1). In the UK, the Feed-In-Tariff with Contract for Difference (FIT-CfD) with the government was recently introduced to support low-carbon generation including nuclear power plants. However, determination of the strike price (guaranteed purchase price) would be a difficult task. In several other countries, a long-term power purchase contract with a group of large industrial customers that may also include joint investment program has been used to help financing nuclear power generators. However, care must be taken in promoting competition and adverse impacts on smaller customers (Y14007).

2 The evaluation of issues and solutions regarding high penetration of renewable energy sources (RES) amidst electricity liberalization

In these reports, we surveyed issues and problems of the process of transmission investment planning, cross-border balancing mechanisms and actual conditions of wholesale trading primarily in Germany. German Transmission System Operators (TSOs) and neighboring TSO of Germany are striving for an international expansion of grid control cooperation. However these TSOs begin to trade off imbalance energy in order to prevent activation control reserve when the available transmission capacity of cross-border transmission lines remains after a wholesale transaction (Fig. 1) (Y14021). Germany's four TSOs and the National Regulatory Authority have cooperatively established a long-term investment transmission plan. The transmission investment increased recently. However the delay of transmission investment increases the cost of congestion management (Fig. 2) (Y14019). In electricity trading, the value of flexibility in thermal power plants as backup for renewable energy becomes more important and is evaluated by financial engineering tools (Y14012).

3 Analysis of the issues in retail competition after full liberalization

We examined the current status and issues of the competition law enforcement by the UK's electricity regulator. To avoid its dual applications by the sector regulators and competition authority, the UK provides for coordination procedures (Fig. 3), which could be a helpful reference for Japan in avoiding overlapping regulations by the new regulatory body and the Fair Trade Commission of Japan (Y14006). Industrial and commercial customers' tendencies to switch electricity suppliers were analyzed based on questionnaire survey. The analysis results showed that, in addition to electricity price, the types of electricity tariffs were important criteria for large customers when selecting electricity suppliers, and that small customers hoped they could consult with retail electricity suppliers and receive energy related services with less trouble. These could make retail competition more active (Y14022). Regarding the U.S. electricity retail market, it has become clear there are some regions considered as competitive, given the transition from regulated tariff to competitive tariff, even if subsidiaries of existing utilities account for most of the competitive tariff market share and that of new entrants is limited.

Table 1: Financing methods for nuclear power plants in major European countries

	FIT-CfD Feed-in-tariff with Contract for Difference	Mankala Model Cooperative with Customers as Shareholders	Long-term Contract with a Consortium of Large Customers	
Country	United Kingdom	Finland	France	Belgium
Counter Party	Government Entity	Large Customers as Shareholders	A Consortium of Large Customers	A Consortium of Large Customers
Contract Summary	Government purchase power by settling the difference between strike price and wholesale reference price	Shareholders are entitled with rights to buy power at cost according to the share	Large customers in the consoritum are entitled with rights to buy power at cost	Large customers in the consortium are entitled with rights to buy power at cost
Scope	New Plant	New Plant	New and Existing Plant	New and Existing Plant
Issues and Concerns	-Strike price needs to be determined by bilateral negotiation without competition. -If the strike price was set too high, burden on taxpayers would increase	-The company is run as non-profit business. -Criticized as "tax evasion system"	-Long-term contract of dominant generator may limit competition -Small customers may be at disadvantages -Only a limited role in financing nuclear power plants	

In Europe, there are financing schemes available for nuclear power plants through long-term contracts with government or large industrial customers. The Feed-In-Tariff with Contract for Difference (FIT-CfD) in the UK is not necessarily a direct subsidy but if the strike price was too high, the government's expenditure would increase. In several other countries, long-term power purchase contracts with groups of large industrial customers have been used to help finance nuclear power generators. These schemes allow the customers to draw the power at a cost, which is assumed to be less expensive than wholesale market prices. However, it may limit the competition in the market by eliminating the opportunity for new entrants. There has also been criticism that small users are disadvantaged.

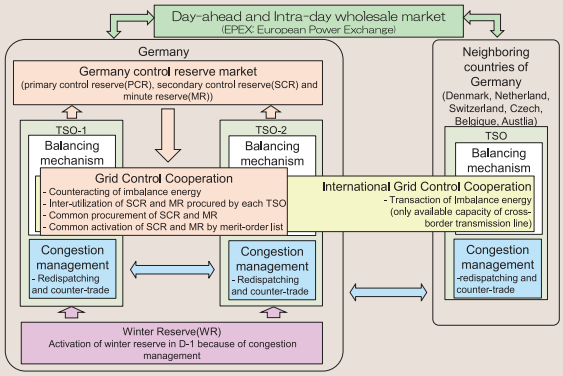


Fig. 1: The balancing mechanism of TSOs of Germany and neighboring countries

The high penetration of RES causes the difficulty of independently balancing each German TSO. After the introduction of GCC, German TSOs have gradually begun to operate GCC from 2008. A German TSO activates redispatching of the output of generators. WR, which is procured through a bilateral contract between TSOs and generator companies, is enforced when it is impossible to solve the transmission congestion by redispatching. IGCC only contributes by preventing activation control reserve by international counter-trading of imbalance energy when there is remaining available transmission capacity following Gate-Closure.

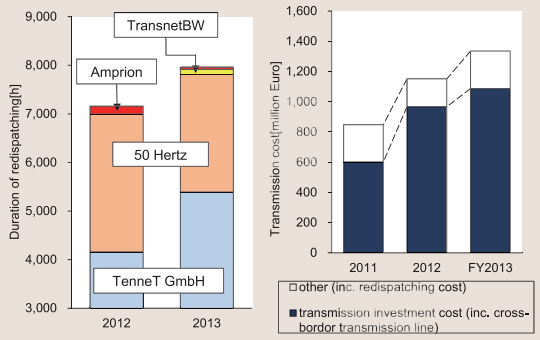


Fig. 2: The change of the transmission cost and duration of redispatching in Germany

German TSOs and the National Regulatory Authority had considered that an upgrade and a new transmission line were necessary in 2009 for the sake of securing supply. A transmission investment was made (right figure). However, in 2014, only 438 km of the enhancement transmission line, which will ultimately have a total length of 1855 km, was complete. The delay of transmission investment and high penetration of RES increase the duration of redispatching of generators by TSOs (left figure). Though the control reserve procurement procedure and the development of transmission network are being carried out in Germany, the cost of securing supply has increased.

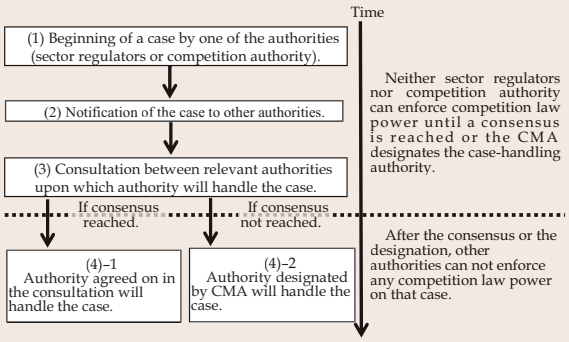


Fig. 3: Procedures to avoid dual applications of competition law by the sector regulators and competition authority in the UK

When granting powers on market competition monitoring and competition protection to the new electricity regulatory body, it is important to avoid unnecessary dual, redundant regulations by the Fair Trade Commission of Japan and the regulatory body. In the UK, since both the electricity regulator (Ofgem) and the competition authority (CMA) concurrently have competition law power, law provides for the procedures to avoid dual applications by these authorities. In particular, (1) when an authority finds a case that could distort competition, and intends to apply competition law, (2) the authority should notify that intent to other relevant authorities. (3) Based on the notification, the CMA and the relevant sector regulators will consult on which authority will handle the case. The case-handling authority will be decided by (4)-1 the consensus between the authorities of the designation by the CMA. This procedure helps to avoid dual application of competition law in the UK.

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

Social and Institutional Analysis of Nuclear Business Environment in Japan

Background and Objective

Taking into account the lessons learned from the Fukushima Daiichi Nuclear Disaster, the institutional environment surrounding nuclear business has greatly changed, such as the independence of the regulatory authority from promotional administrative agencies. Electric power companies, who are the main bearers of the nuclear business, must not only carry out institutional analysis but also obtain an accurate picture of social consciousness, which is one of the great driving forces behind the environmental change, in order to be able to steadily respond to the change.

This investigation analyzed social consciousness to forecast the direction of future institutional reforms in the Japanese nuclear industry, and provided case studies of how the nuclear industry in foreign countries or other industries in Japan cope with institutional environment change in order to obtain implications for the nuclear business in Japan.

Main results

1 An investigation of the current status and changes of social consciousness relating to environmental and energy issues after the Great East Japan Earthquake

Through a social survey (3600 men and women in 11 cities across Japan), we grasped public opinion in regards to environment and energy issues (Fig. 1), public attitude toward energy-related organizations including electric power companies (Fig. 2) and the points that the general public thinks are important in assessing nuclear power technology, comparing the previous survey results to those of past years. (Fig. 3) (Y14004). We analyzed the results of the survey and proposed important points for electric power companies to communicate with local people and general public. The important points are as follows: 1) it is important for the electric power companies to make an appeal the public interest in general energy issues such as energy security before acquiring public understanding regarding the companies' activities; 2) it is useful for electric power companies to provide information and maintain communication with the public, "customizing" their interests, knowledge, and behavioral patterns; 3) it is important for electric power companies to understand energy issues including nuclear power that concern the public and appreciate the importance of restoring public trust.

2 An analysis of overseas meetings in nuclear siting areas

Some local stakeholder meetings have been established at nuclear siting areas in the UK and France. In the UK, a primary role of SSG (Site Stakeholder Group) is improving the quality of decision-making and risk management in operators through local stakeholder engagement. On the other hand, CLI (Commission Locale d'Information) in France contributes to ensure transparency through information sharing and communication among electric power industries, regulatory bodies and local communities. (Table 1) However, in the case of both stakeholder meetings neither have the authority to permit the operation (including re-start) of nuclear facilities, nor play the role of "consensus building" in regards to controversial nuclear power issues. We showed that it was preferable for nuclear power policy and electric power companies in Japan to clarify the institutional position of such stakeholder meetings in local government and to reflect opinions of the local stakeholders.

3 A trend analysis of stakeholder meetings in non-nuclear fields

In Japan, some stakeholder meetings have been established in non-nuclear fields. We analyzed these stakeholder meetings and clarified two trends of the meetings (Table 2). The two clarified trends are as follows: 1) proposal-type meetings tend to illustrate a concrete direction and assessment of the siting points, and opinions expressed at such meetings have influence on final decision-making of the business activities; 2) monitoring and dialogue-type meetings don't focus on short-term and directive consensus building but rather on forming medium and long-term relationships of trust. It is preferable for nuclear fields in Japan to utilize the latter option.

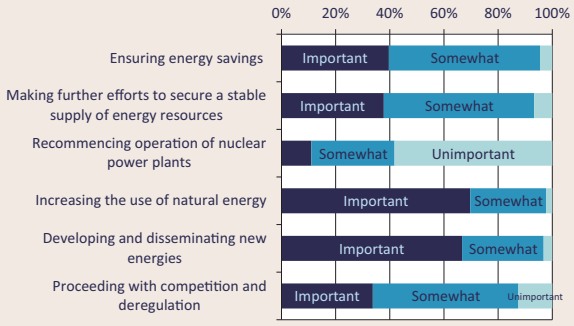


Fig. 1: Important aspects of energy policy in Japan

Expectations towards the utilization of natural energy and new energy are high, and support to restart nuclear power generation is low.

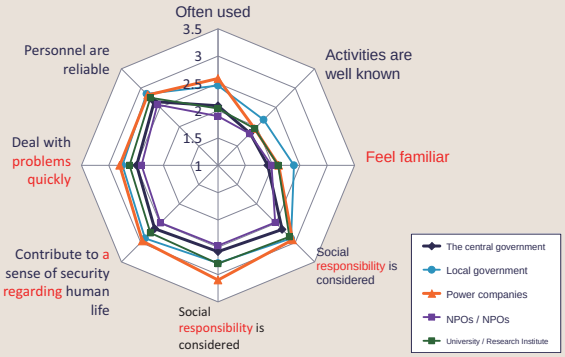
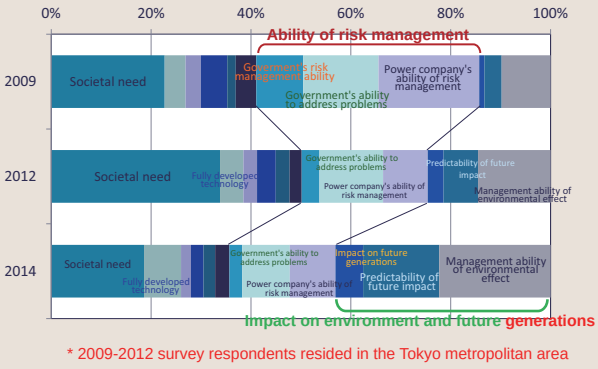


Fig. 2: Public attitude towards energy related organizations

The public has less confidence in the electric power industry and is not aware of their activities. Despite this, the public does appreciate the electric power industry as a contributor to a secure and affluent daily life.



* 2009-2012 survey respondents resided in the Tokyo metropolitan area

Fig. 3: The most important criterion for evaluation of nuclear power generation

Before the earthquake of March 2011, "risk management competence" was the most common answer, but now, "impact on the future and environment" is considered the most important criterion.

Table 1: Comparison of site stakeholder meetings in the UK and France

	SSG (Site Stakeholder Group)	CLI (Commission Locale d'Information)
Major role	Quality improvement of decision-making and focusing on "input" through participation	Ensuring transparency through information-sharing and communication among stakeholders
Key characteristics	・Providing the fields of participation for "consultation" in planning ・including issues regarding economy/employment in the area	・Stipulating the duty of providing information to CLI and the right to ask questions from CLI ・Being able to consider that municipalities are integrated into regulatory system
Influence over decision making	Substantially powerful influence over decision-making by NDA/operators	Distinguished discussion in CLI on decision-making by operators.
Legal base	NDA guideline; not legal binding	Law 2006-686 of 13 June 2006 concerning nuclear transparency and safety with decree
Chairman	Ex. local chief executive etc	Prefectural assembly chairman of the local area
Budget	From NDA	From utility
Regional coverage	Allocated depending on each issue	Distinction by emergency planning zone

In the case of both stakeholder meetings, neither have the authority to permit the operation (including re-start) of nuclear facilities, nor play the role of "consensus building" in regards to controversial nuclear power issues.

Table 2: Stakeholder meetings of non-nuclear fields

	Proposal-type	Monitoring/dialogue type
Key characteristics	・Illustrating a concrete direction in planning, policy, potential siting area, and assessment results concerning selecting sites for waste treatment centers, etc.	・Mainly explaining and providing information from operators/administrative bodies ・Not focused on short-term and directive consensus building but rather on forming medium and long-term relationships of trust
Influence over decision-making	Opinions expressed at meetings have influence over the final decision-making by operators	Good proposals in meetings are properly reflected by operators/administrative bodies
Major challenges	・How to respond to directions which differ from what administrative bodies etc. originally thought. ・The recognition gap of position of the meetings in administrative bodies.	・The purpose of the meetings are questioned if the stakeholders believe their opinions are not reflected ・Tend to be substantially explanation-oriented meetings
Cases	・River basin committee ・Committee for waste treatment plant and crematorium etc.	・Monitoring committee for PCB disposal ・"Responsible care" in chemical industries ・Council for US military bases

Proposal-type meetings tend to offer a concrete direction and assessment of the siting points, and opinions expressed at such meetings have influence on the final decision-making regarding business activities. On the other hand, monitoring and dialogue-type meetings don't focus on short-term and directive consensus building but rather on forming medium and long-term relationships of trust.

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

Climate Change Policy

Background and Objective

Nations are negotiating a new international framework to combat climate change post-2020 and discussions on CO_2 reduction targets, country policy and measures are underway in Japan.

We examine the effectiveness of policy and measures to combat climate change that are compatible with economic development and energy security.

Main results

1 Integrated analyses of policy and measures to combat climate change

We analyzed the feasibility and costs of the 2 degree C target put forward by the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report, to which our member contributed as a Coordinating Lead Author, and found that the economic and political challenges to meet the target are enormous. We also examined the Japanese policy package and identified the role of voluntary action by the industry as a policy instrument that compliments other policy and measures such as direct regulation and energy taxes. These findings were presented and incorporated in the governmental councils which consider Japanese climate policy. (Figures 1 and 2).

2 Regulating carbon pollution emissions from power plants in the United States

Ongoing rulemaking to limit carbon pollution emissions from the U.S. power sector provides a useful reference for Japan to consider approaches to climate change mitigation. CRIEPI examined the details of the Clean Power Plan (CPP), which was proposed on June 2, 2014, to cut carbon emissions from existing power plants. We have summarized the key components of the CPP as follows. I) Proposed CPP expects deep cut of carbon pollution from power sector assuming drastic fuel shift from coal to gas, which is feasible in the U.S. due to low-priced natural gas resources. II) There is high uncertainty and significant downside risks surrounding the CPP, which derive from a court order issued against the scope of legal power or authority (see Fig. 3) (Y14005).

3 International climate negotiations

In 2014, the scope of the intended nationally determined contribution (INDC) was a contentious issue. Most developed countries thought the scope should be mainly mitigation, while many developed countries insisted that INDC should cover not only mitigation but also adaptation and support for them. At COP20, the Parties agreed to include mitigation in their INDCs and also to include adaptation at their discretion. With regard to mitigation, the Parties presented their views on many issues such as (1) target year/cycle, (2) a way to register their contributions, (3) the legal nature of contributions, and (4) rules for transparency (Table 1). In 2015, in order to obtain consensus agreement at COP21, the Parties need to consider difficult issues such as (1) balance among mitigation, adaptation and support, (2) participation of the United States, and (3) consistency with the 2 degrees goal (Y14020).

4 Energy efficiency policy

Increasing energy efficiency is considered to play a major role in reducing greenhouse gas emission. Based on our extensive surveys we make four recommendations: energy efficiency policy should be conducted only when it can remove market failures or barriers cost-effectively; the behavioral approach should be utilized more; energy management regulation by the Energy Conservation Law should be reformed into a more informational approach in order to reach small-and-medium-sized companies; subsidy programs for energy efficient investment now amounts to 200 billion JPY, and some have low cost-effectiveness (Fig. 4), thus require strict evaluation.

Carbon pricing: Changes cost calculation	Promote rational behavior : Fix information asymmetry and lack of coordination	Long term investment:
Tax, ETS*,..	Energy conservation law Voluntary Agreement	Tech development policy

Fig. 1: Role of Voluntary Action

The role of voluntary action by the industry of Japan as a policy instrument is identified as a complimentary policy to the other policy instruments such as carbon pricing and energy conservation law.

Fig. 2: IPCC report to which CRIEPI contributed and the book "Dealing with Global Warming"

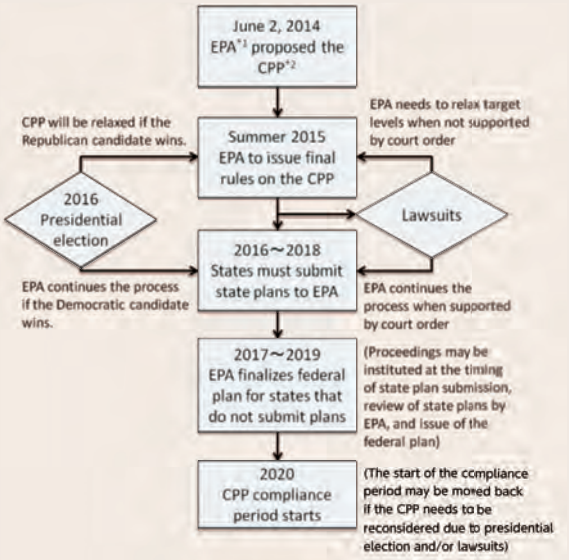


Fig. 3: Upcoming milestones and key events for finalizing the Clean Power Plan

The CPP needs to go through several steps shown in the above rectangles. Key events that influence the whole schedule are indicated in the rhombi.

*1 the U.S. Environmental Protection Agency
*2 Clean Power Plan

Table 1: Issues relating to mitigation and views of the Parties

Issues	Views of the Parties
Target year/ cycle	① 10-year cycle (Japan, EU, Canada, South Korea, India and others) ② 5-year cycle (US and others) ③ 5-year commitment with indicative commitment for subsequent five years (Brazil, South Africa)
Legal nature of contributions	① Legally-binding (EU, least developed countries (LDC) and others) ② Non-binding, but binding obligations to submit contributions, implement measures aiming to achieve them, and be exposed to ex-post review (Japan) ③ Non-binding, but binding obligations to submit contributions and be exposed to transparency measures and domestic legal force for measures aiming to achieve contributions. (New Zealand, US)

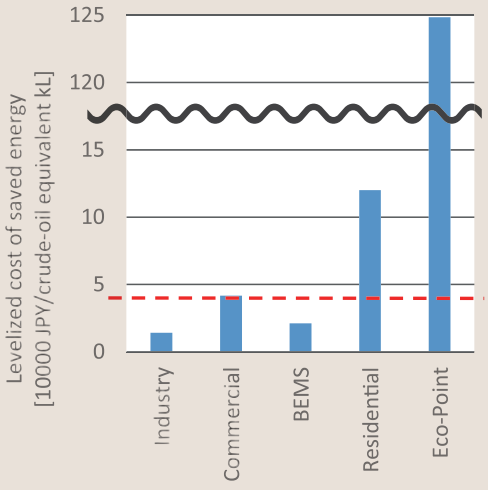


Fig. 4: Cost-effectiveness of selected energy efficient subsidy programs

Our estimation of levelized cost of saved energy shows that, while costs of several programs are lower than the avoided cost of energy, others show much higher costs.
*1, *2, *3) CRIEPI Report (Y13028), *4) Estimation by CRIEPI, 5), Arakawa & Akimoto, J. Japan Inst. Ene., 94., (2014),

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

Scientifically and Economically Rational Scenarios for Reducing CO_2 Emissions

Background and Objective

While we do not have a clear outlook for the national energy policy, reduction of CO_2 emissions is a major international issue of some urgency. Although scientific findings on global warming, which form the basis of emissions reduction, include inevitable uncertainties, they should be appropriately updated in a rational plan of emissions reduction. Regarding low-carbon technologies, which can lead to emissions reduction, we need to select an appropriate direction for their development based on the latest technology trends and associated potential risks.

This study investigated in detail the limitations of global CO_2 emissions from a scientific viewpoint and provides a reasonable prospect of low-carbon transformation based on technology availability, and thus aims to contribute to the establishment of a long-term national energy policy. We also conducted an assessment of various risks regarding carbon dioxide capture and storage (CCS) to discuss the future adoption of CCS technology.

Main results

1 Explication of the latest findings of the Intergovernmental Panel on Climate Change (IPCC)

The IPCC Fifth Assessment Report (AR5) published in 2013–14 has updated the relationship between the risk level of climate change and the global temperature increase, which forms the basis of the long-term goal of emissions reduction of CO_2 and other gases. Generally speaking, the updated risk level is assessed with greater confidence and is higher than that of the Fourth Assessment Report released in 2007. We have investigated in detail this information and found that the AR5 updates are connected with its wider scope of risks and associated socio-economic factors in addition to new climate observations and projections (Fig. 1) (V14012). The dependency of the risk level on socio-economic factors implies that the restriction of CO_2 and other gases emissions could vary with the direction of global socio-economic development.

2 Improvements in our energy-economy-climate integrated assessment model

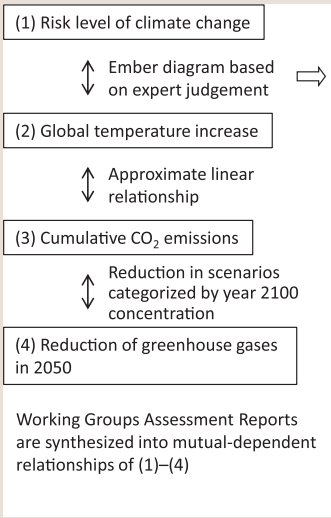
Arising from difficulty of substantial emissions reduction in the near future, long-term scenarios of reduction of CO_2 and other gases assessed in AR5 seriously consider technologies to realize negative emissions (net absorption) in the far future on a century time scale, such as power generation by biomass energy with CCS. To make a detailed investigation of future technology potential in tandem with the uncertainties of climate projection, we have improved our existing integrated assessment model and simple climate model*1. The improved integrated assessment model includes updated parameters, such as efficiencies and unit prices of power generation facilities, new energy pathways to deal with hydrogen and other innovative technologies, and an interface to be coupled with our existing biomass model (Fig. 2). The simple climate model has been improved to deal with the uncertainties of climate sensitivity*2 (Fig. 3). These models will be used for studies on feasible long-term (year 2050) goals to contribute to the establishment of a long-term national energy plan.

3 Elucidation of CCS technology and associated policy developments

We have surveyed recent CCS projects around the world. Regarding coal-fired power plants with CCS, although the Boundary Dam project in Canada has started operation in commercial use with financial support from the government under its CO_2 emissions regulation (implemented July, 2015), progress on a global scale is not observed (Table 1). Because CCS business entails uncertainty in regards to profitability, political or financial support from governments and mechanisms of cost compensation by selling captured CO_2 are essential for making CCS commercially viable. Meanwhile in our national circumstances, we have found that the public's awareness on current electricity generation mix and low carbon technologies such as CCS is low, and that there are various public opinions about the development of thermal and nuclear power generation. These findings imply the need for a broad social understanding about the domestic energy situation and the significance of climate change countermeasures in the discussion of CCS introduction.

*1 Model improvements were supported in part by the Program for Risk Information on Climate Change from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

*2 A physical parameter to quantify the temperature change by heating or cooling effects of various climate change factors. It is commonly defined as an increase in the global mean temperature due to doubling of the atmospheric CO_2 concentration. The temperature increase following doubled CO_2 concentration in the equilibrium state is different from that in a transient state, and two parameters termed equilibrium climate sensitivity and transient climate response are defined, respectively.



Item	Description
Ember diagram	Five bars representing RFCs (the next item) with the scale of the temperature increase colored by gradation of white, yellow, red, and violet in order corresponding to four risk levels, provided to facilitate judgment about "dangerous anthropogenic interference" of the United Nations Framework Convention on Climate Change.
RFC (Reasons For Concern)	Five elements of climate change risks categorized from a cross-cutting perspective over different sectors and regions. RFC1: unique and threatened systems (sea ice, coral reef, etc.), RFC2: extreme weather events (heat wave, heavy rain, etc.), RFC3: the distribution of impacts (food and water security, etc.), RFC4: global aggregate impacts (economic loss, etc.), RFC5: large-scale singular events (melting ice sheet, etc.).
Climate change risks	Considered as results from the interaction of physical hazards and socio-economic factors. Risk levels are evaluated based on findings from the detection and attribution of associated impact considering the degree of confidence as well as documented criteria for key risks.
AR5 assessment	The risk levels assessed in AR5 are increased from those in the previous report as a whole except for RFC4. This update is connected with its wider scope of risks and associated socio-economic factors in addition to new climate observations and projections.

Fig. 1: Main points of AR5 (left) and assessment of climate change risks (right)

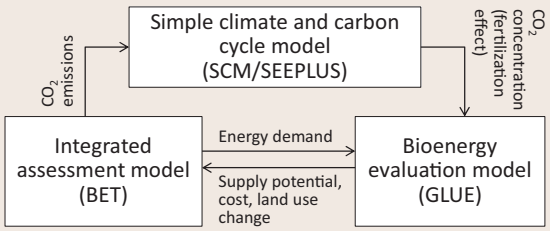


Fig. 2: Models for studies on CO_2 emissions reduction goals

Model names are shown in parentheses. SCM is a model to calculate the global mean temperature and CO_2 exchange between the atmosphere, ocean, and land, and SEEPLUS is a web-application to deal with SCM. BET is an integrated assessment model representing mutual dependency between energy, economy, and climate. GLUE is a model to calculate energy flow associated with biomass.

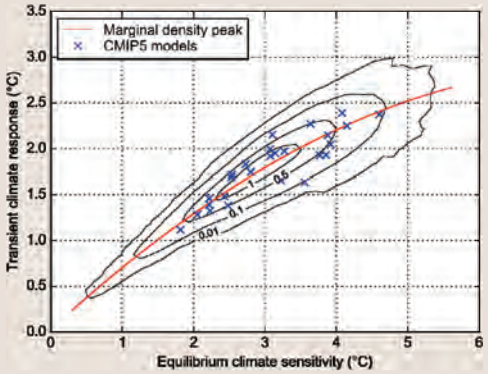


Fig. 3: Probability density of equilibrium climate sensitivity and transient climate response

This study considers the variation of multiple complex climate models (termed CMIP5 models, Fig. 3) assessed in AR5 and formulates uncertainties about climate response represented by the both sensitivity parameters. This formulation has been incorporated into SCM (Fig. 2), which enables evaluation of the temperature calculation in light of the uncertainty range of the CMIP5 models as well as AR5 assessment for climate sensitivity.

Table 1: Worldwide CCS projects suspended or delayed (2012–2013)

Project name	Country	Project phase	Reasons
< Cancelled project >			
PurGen One	USA	Just before final investment decision	Investment decision
Belchatów	Poland		lack of finance
Taylorville Energy Center	USA		Changing economics and the lack of legislation
Tenaska Trailblazer Energy Center			
Cash Creek		Feasibility study	Changing of the plan to build a natural gas combined cycle facility
< On hold project >			
Swan Hill Synfuels	Canada	Just before final investment decision	Dependent on natural gas prices
Hydrogen Power Abu Dhabi	UAE		Prioritizing investment in other projects
Green Hydrogen	The Netherlands	Just before final investment decision	Submission not supported in the NER300's first round*
Eemshaven CCS			
Pegasus Rotterdam			
Southland Coal and Fertiliser	New Zealand		Prioritizing investment in other projects
Bulgaria	Bulgaria	Front-end engineering design study	Unspecified

*NER300 is one of the world's largest funding programmes for innovative low-carbon energy demonstration projects. It is conceived as a catalyst for the demonstration of environmentally-safe CCS and innovative renewable energy technologies on a commercial scale within the EU. It is funded from the sale of 300 million emission allowances from the New Entrants' Reserve set up for the third phase of the EU emissions trading system (EU ETS).

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

Structural Integrity Evaluation of Reactor Pressure Vessels and Core Internals

Background and Objective

In order to accomplish the safe and stable operation of LWR plants, we will enforce the technical basis for structural integrity of reactor pressure vessels (RPVs) and core internals through better understanding of various degradation mechanisms together with the development and the improvement of evaluation methods. In this project, we have conducted the following research.

Main results

1 Development of applied techniques for fracture toughness evaluation of actual plant components by the Master Curve method

A fracture toughness evaluation method by the Master Curve method using miniature specimens, which can be made from broken halves of Charpy impact test specimens, was developed. The international round robin test was conducted and the results are comparable among the organizations (Fig. 1). Distribution of the fracture toughness data conforms to Weibull distribution which is assumed in the Master Curve method and is equivalent to that of the standard 1-inch thick specimens [1][2] (Fig. 2). The results establish the efficiency of the Master Curve method using the miniature specimens.

2 Study on strength evaluation for penetrations of nuclear pressure vessels

It is likely that penetrations in the bottom of reactor vessels were damaged by the effect of core melting, causing the leak of melted fuel from the vessels in Units 1 to 3 of Fukushima Daiichi nuclear power plant. Evaluation of the damage process requires estimation of temperature history and stress/damage analysis for the penetrations to be made. We developed constitutive models to estimate stress-strain relationship of the three materials used for RPVs (Fig. 3) (Q14016).

3 Improvement in the method for integrity evaluation of irradiation embrittlement in RPV steels

Atomistic scale observations by atom probe tomography on thermally aged or neutron irradiated Fe-Cu-Ni-Mn quarternary alloy simulating RPV steels were conducted*. Solute atom clusters were formed in all the materials, however Ni and Mn composition in the clusters differed between the thermally aged and irradiated materials indicating differences in cluster formation mechanisms (Fig. 4).

* Collaboration with the University of Tokyo.

[1] M. Yamamoto et al., Procs. ASME 2013 Pressure Vessels & Piping Division conference, PVP2013-97936 (2013).
[2] M. Yamamoto et al., Procs. ASME 2014 Pressure Vessels & Piping Division conference, PVP2014-28898 (2014).

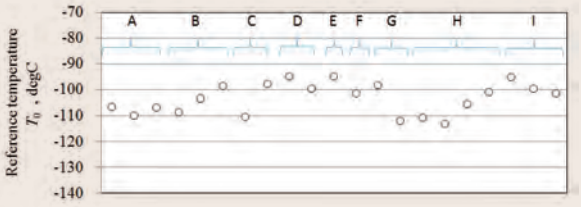


Fig. 1: Comparison of reference temperature obtained from the international round robin testing

This compares the reference temperature obtained from the same RPV steels among various organizations. All results are comparable independent of the organizations (A~I indicate the respective organization).

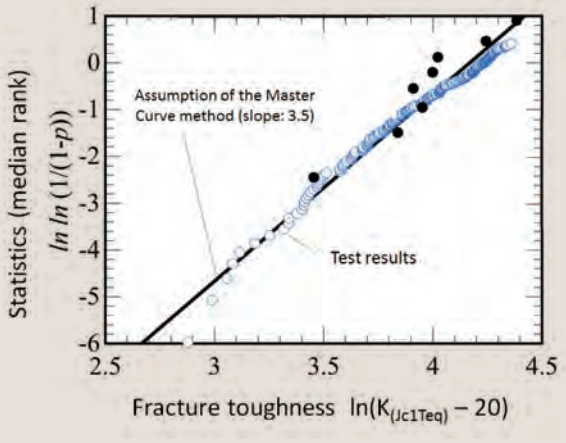


Fig. 2: Statistical plot (Weibull plot) of the fracture toughness data

The Master Curve method assumes that distribution of fracture toughness data conforms to Weibull distribution. All the data obtained in the international round robin test shows good agreement with the assumption.

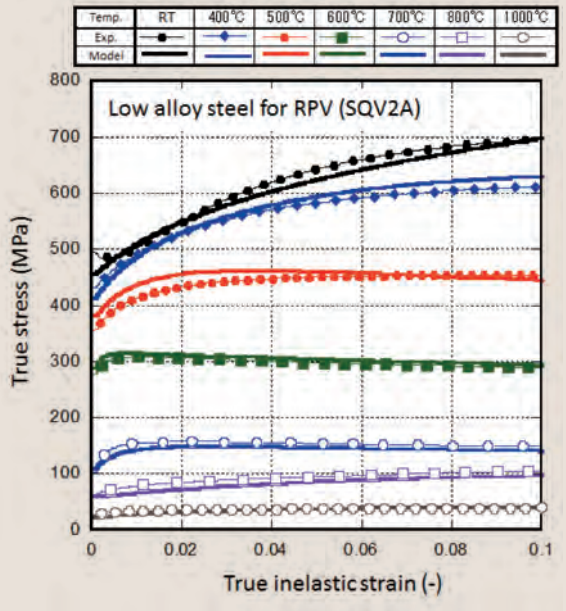


Fig. 3: Stress strain curves obtained by the experiments and the constitutive modeling developed in this study

This figure shows stress-strain curves obtained from the tensile tests at various temperatures and the simulations by the model developed. The model reproduced the experimental results with good accuracy.

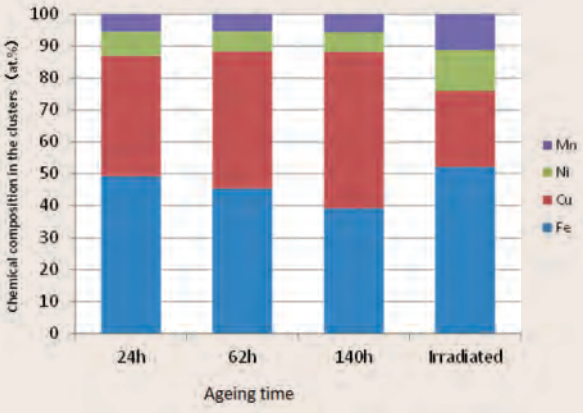


Fig. 4: Comparison of chemical compositions of the solute atom clusters formed in the Fe-Cu-Ni-Mn model alloys

Solute atom clusters were formed in the Fe-Cu-Ni-Mn model alloy after thermal ageing at 450℃ or neutron irradiation. However the amount of Ni and Mn in the clusters of the thermally aged alloys is smaller than that in the irradiated alloy and independent of ageing time. This indicates a difference in cluster formation mechanisms between the aged and irradiated alloys.

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

Evaluation of Components and Piping Integrity in LWRs

Background and Objective

This subject will contribute to stable operation by developing components and piping integrity evaluation methods as a part of maintenance technology for improvement of structural material reliability and aging prediction accuracy for LWRs, and for raising safety of maintenance and inspection personnel.

Main results

1 Evaluation of Tensile Properties of Safety-Conscious Rolled Steels for Building Structure (SN Steels) at High Temperature

Rolled steels for general structure (SS steels) are generally used for support structures in nuclear power plants. Meanwhile rolled steels for building structure (SN steels) could be alternative steels from their high weldability and toughness. To make the use of SN steels possible, comprehensive tensile properties up to 400°C were evaluated for the incorporation of SN steels into the JSME material code, and additional tensile properties up to 650°C were evaluated for the structural integrity assessment under severe accident conditions. The effect of temperature on the yield stress or tensile strength was similar in spite of the differences in material type or plate thickness, and the difference due to different charge*1 was limited (Fig. 1). Based on the results, the approximated equations of the trend curves both for design yield stress and design tensile strength at high temperature normalized at room temperature were derived, and these can be incorporated into the JSME material code (Q14006).

2 Verification of Pipe Wall Thinning Prediction Software, FALSET

Pipe wall thinning prediction software, FALSET, was verified for comparison with pipe wall thickness measurement data in Japanese LWRs. As a result of a comparison with FAC data in condensate and feedwater lines (water single-phase system) of 4 PWRs (980 data), where 1 PWR was newly added, FALSET demonstrated a prediction accuracy with an error margin of approximately 10% for residual wall thickness of elbow elements comparing to recent measurement thickness (Fig. 2). It was confirmed that management for pipe wall thinning with prediction by FALSET could be conducted conservatively for most piping elements except for those in low temperature conditions with low thinning rates.

3 Evaluation of Thermal Aging Embrittlement of Cast Austenitic Stainless Steel

Cast austenitic stainless steel (CASS), which is used for the pump casing and the primary coolant pipes in LWR, is susceptible to thermal aging embrittlement*2. In order to quantitatively evaluate the thermal embrittlement, CASS (JIS SCS16A) aged at 300-450°C for up to 15,000 hours was investigated using an elastic-plastic fracture toughness test and hardness test. As a result of the tests, it was found that the fracture toughness tended to decrease as aging time increased. On the other hand, the hardness of ferrite phase tended to increase as aging time increased (Fig. 3). Relatively good correlation was observed between the fracture toughness value and hardness of ferrite phase. This result suggested that the fracture toughness can be estimated from the hardness of ferrite phase.

4 Development of Dispersant Technology in LWR Primary Systems

Dispersant technology is considered to be promising in reducing the radiation intensity of LWRs. As a part of the dispersant technology development, radiolysis of PAA (polyacrylic acid) solution was investigated. After gamma-ray irradiation, the yields of carbon dioxide and acetate were highest in the carbon-containing products. But, the concentrations of carbon dioxide and acetate were much lower than the initial PAA concentration. The radiation chemical simulation of PAA solutions implied that scission of PAA radicals*3 is the major process in the radiolysis of PAA (Fig. 4). No radiolytic products harmful to structural materials in LWRs were found (Q14014).

*1 Molten steel extracted from particular ladle furnaces.
*2 Transition of material property with time when exposed to certain temperature conditions.
*3 PAA radical is polyacrylic acid molecule with unpaired electron(s).

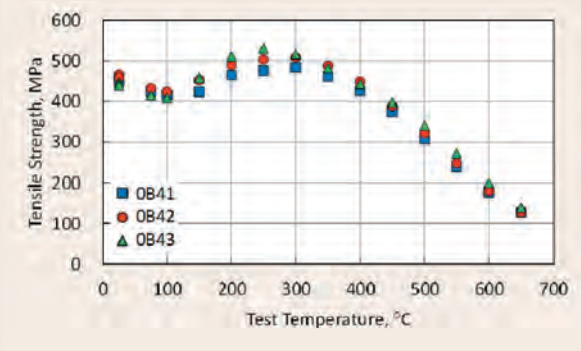


Fig. 1: Effect of test temperature on tensile strength for SN steel (SN400)

Tensile tests were conducted for 40 mm thickness SN400B steel with three different charges under strain rate condition compatible with the JIS standard (0.00007/s before yielding, 0.0014/s after yielding). Different charges gave similar tensile properties.

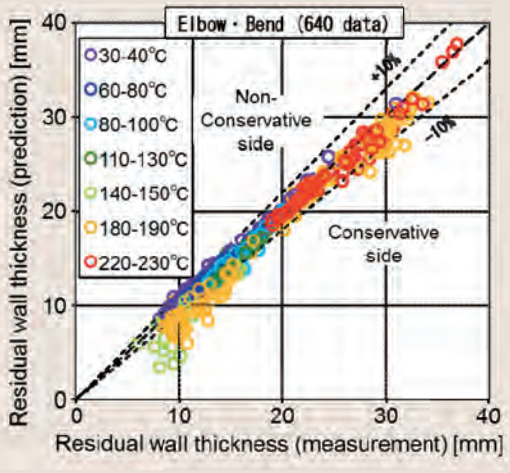


Fig. 2: Prediction accuracy for residual wall thickness of 4 PWRs' elbows by FALSET

Prediction accuracy for residual wall thickness was verified with FAC data of 640 elbows in condensate and feedwater lines of 4 PWRs, and more than 99% of the data could be predicted under +10% (non-conservative side) comparing to recent measurement thickness.

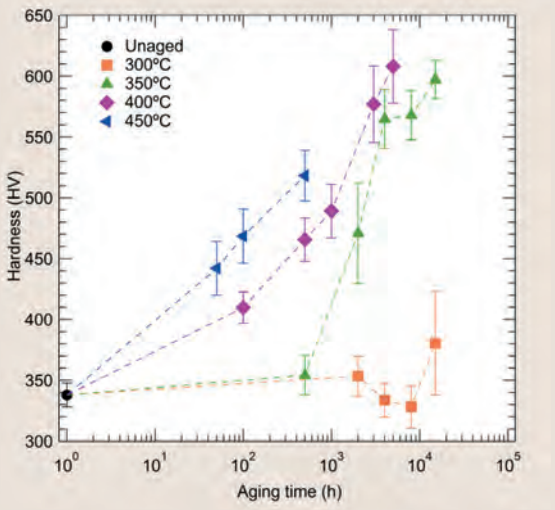


Fig. 3: Relationship between hardness of ferrite phase and aging condition

Hardening began at an earlier stage at high temperature. The change of hardness was obvious after 15,000 h in the specimen aged at 300°C.

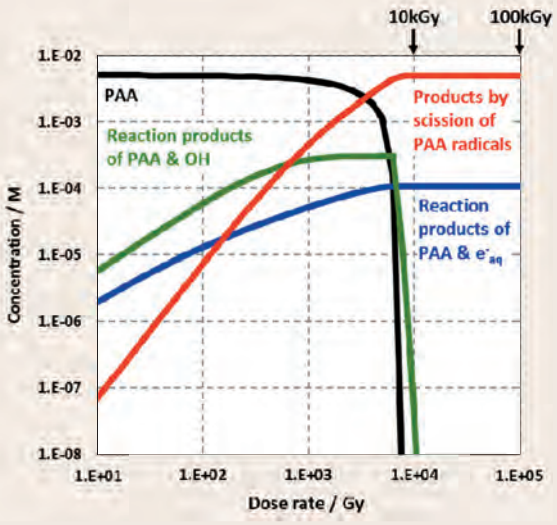


Fig. 4: Results of radiation chemical simulation of PAA solution (PAA 500 ppm, 300°C, neutral pH)

Scission of PAA radicals is the major process up to several kGy. PAA is consumed at about 5 kGy. It seems that disproportionation of PAA radical is dominant at higher absorption dose due to the fact that slow change in molecular weight of PAA was observed.

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

Evaluation of Insulation Properties of Cables Used in Nuclear Power Plants

Background and Objective

In order to establish safe and stable operation of nuclear power plants, integrity evaluation methods are important for materials aged during their service operation under heat and radiation environments. In regards to the aging of polymeric insulating materials used for instrumental and control cables installed in containments, discrepancies between actual aging during the service operation and aging predicted using a conventional manner are reported[*1, 2].
The objective of the present study is to improve this conventional prediction method by considering several effects under normal plant operation conditions. Knowledge and information obtained in this study is anticipated to improve the lifetime evaluation, thus contributing to safe operation of nuclear power plants.

Main results

1 Aging trend of cable insulating materials during normal service operation and possible mechanism of material degradation

A statistical analysis was conducted for the data of elongation at break[*2] obtained for the service-used cable insulations. As a result, the aging trend in service is found to be approximately slower by half than that expected from acceleration aging test results (Fig. 1)[*3]. Such service-used cables were subjected to additional thermal aging[*4], which was induced by the wear-out approach[*5] (H14002). Obtained results were compared with the degradation behavior of corresponding control material subjected to acceleration aging (Fig. 2). The rate of degradation is three times slower than that predicted on the basis of an acceleration aging test in control samples. Instrumental analyses show that the unique slow dynamics in the service cables is considered to be due to oxidation control and cross-linking reaction[*5], which may be affected during the service duration. It follows that usage history such as low concentration environment in boiling water reactor containment is necessary to improve the aging prediction method.

2 Study on acceleration factor of acceleration aging tests

Acceleration aging tests for safety cables are implemented by combinations of heat and radiation. Therefore, it is important to accurately estimate the acceleration factors. Simultaneous applications of the two factors with high dose rates up to 1000 Gy/h were conducted against flame-retardant ethylene-propylene rubbers; where low dose rate acceleration tests of the corresponding material were already reported[*1]. Analytical parameters for the acceleration factor found only under low dose rate conditions were optimized to be explainable also for degradation behaviors under high dose rate radiations (Fig. 3). From such investigations, more conditions of accelerated aging tests become applicable to material aging estimation.

*1 Japan Nuclear Energy Safety Organization, JNES-SS-0903, 2009 (Assessment of Cable Aging for Nuclear Power Plant, ACA project).
*2 Y. Eguchi, presented at 2012 Equipment Qualification Technical Meeting, San Antonio, TX, 2012.
*3 N. Fuse et al., IEEE Trans. Dielectr. Electr. Insul., 21(5), 2012-2019, 2014.
*4 Additional thermal aging conditions were determined by considering the degradation level, which is equivalent to radiation aging.
*5 K.T. Gillen and M. Celina, Polym. Degrad. Stab., 71(1), 15–30, 2001.
*6 A chemical reaction that links one polymer chain to another. Generally, elasticity is lost due to the brittleness of rubber materials.

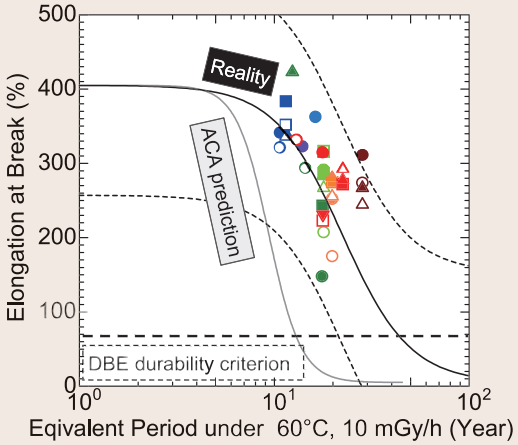


Fig. 1: Comparison of aging trend statistically analyzed for service-used cables (colored plots) and prediction (gray curve)

Data shift was conducted for statistical analysis using the superposition of time-dependent data procedure with activation energy of 19 kJ/mol. The black solid curve and the two broken curves represent fitted logistic curves and its 95.4% prediction band, respectively. The gray curve is a prediction from an acceleration aging test*1. DBE durability criterion is represented by the horizontal line.

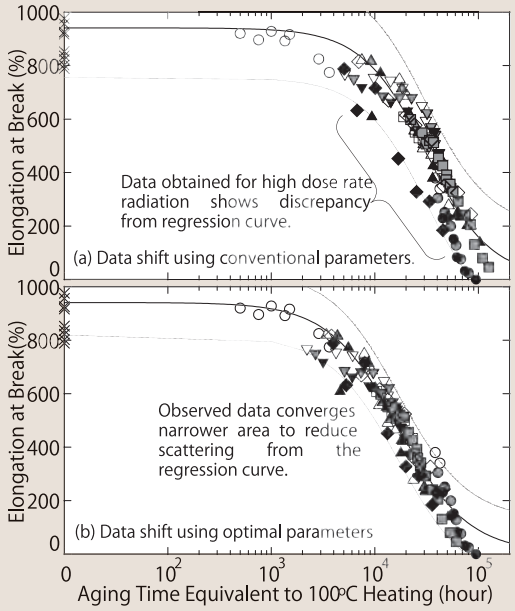


Fig. 3: Aging trend of elongation at break in frame retardant ethylene propylene rubbers

Data shift of aging time was conducted using analytical parameters of a conventional set (a) and those optimized in the present study (b). ×: before degradation. Other plots are obtained from acceleration aging test varying with dose rates, temperatures and degradation time (0-1050 Gy/h, 80-120°C, 0-42481 hours).

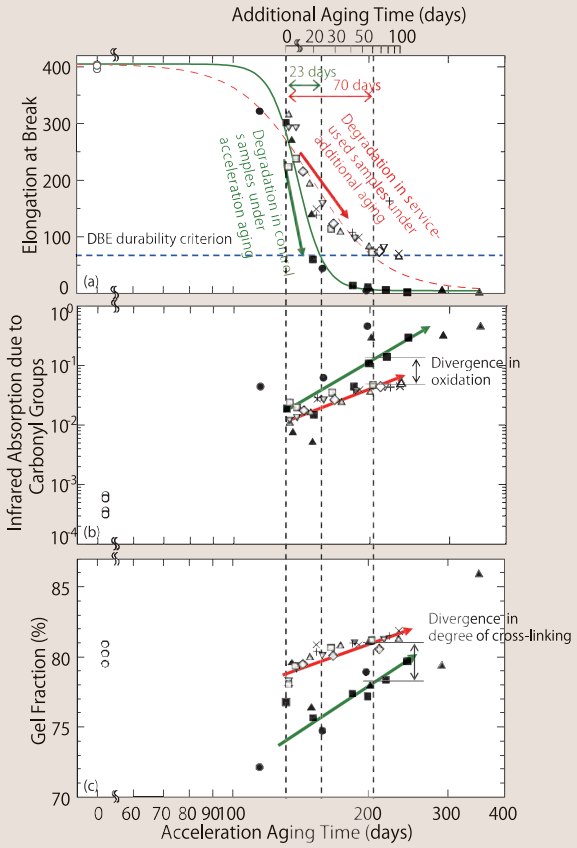


Fig. 2: Comparison of aging trend for control samples (solid symbols) and for the corresponding materials used for 16 years of service operation under BWR containment (open symbols)

Comparisons are shown for aging trends of elongation at break (a), carbonyl index (b), and gel fraction (c). Both acceleration aging for control samples and additional aging for service-used samples were conducted under the 110°C-thermal condition without radiation. Open circles represent initial value. Two curves in (a) are regression results using the logistic formula. Carbonyl index in (b) is absorbance at 1720 cm^{-1} normalized by that of 2920 cm^{-1}, measured by Fourier transform infrared spectroscopy.

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

Development of Nondestructive Inspection Technologies for Components and Piping in Nuclear Power Plants

Background and Objective

For the sake of appropriate maintenance and securing the safety of electric power facilities including nuclear power facilities, the nondestructive inspection of defects in metals used in such facilities is important.

In this project, optimum NDE technologies are developed for important components related to the safety of light-water reactors to enhance their operational safety. Meanwhile, the standardization and implementation of a PD system[*1] for these technologies are also taken into consideration.

Main results

1 Development of depth sizing technique of cracks in dissimilar metal welds

Inspecting dissimilar metal welds (DMW: joint of low alloy and stainless steels with nickel based alloy weld), such as vessel nozzle to piping welds, is extremely difficult due to the difficulty in the detection of a crack tip echo of SCC (Stress Corrosion Cracking). A technique for determining a crack shape using the reflection of ultrasonic waves at the surface of the crack via phased array technology[*2] has been developed (Fig. 1). By using the technique, the identification of the crack tip echo from material noise becomes much easier and the crack depth sizing becomes more accurate.

2 Prototype of a virtual testing system for ultrasonic examination engineers

The skill of examination personnel usually influences the reliability of inspection results, particularly in manual ultrasonic testing (UT). For PD examination and the training of examination personnel, numerous test specimens with various defects are necessary. To reduce cost and improve the effectiveness of the training and PD examination, a prototype of a virtual UT system simulating actual UT work of piping welds was developed (Fig. 2); performing ultrasonic testing virtually on specimens without defects is possible because the system makes use of ultrasonic signals acquired from actual test specimens. The system provides the potential for effective training and examination (Q14007).

3 Modeling for initiation behavior of stress corrosion cracking for sensitized stainless steel

To establish a modeling for initiation behavior of stress corrosion cracking for determining an appropriate inspection interval, a calculation technique, which could evaluate crack depth distributions, has been developed for the simulation model based on coalescence and growth of micro cracks[*3]. Since calculations that reproduce experimental crack depth distributions have not been reported, crack depth distributions were calculated using this technique. Crack depth distributions obtained from the calculation, assuming that cracks start growing with constant growth rate when stress intensity factors at crack tips exceed a threshold value, conformed to a normal probability distribution and well reproduced experimental results for sensitized stainless steel[*4] (Fig. 3) (Q14013).

*1 Performance demonstration system for ultrasonic examination.
*2 Ultrasonic phased arrays use multiple ultrasonic elements and electronic time delays to control ultrasound propagation by interference.
*3 K. Tohgo, H. Suzuki, Y. Shimamura, G. Nakayama, and T. Hirano, Corrosion Science, 51, 2208-2217, 2009.
*4 M. Akashi and T. Kawamoto, Boshoku Gijutsu, 32, 9, 1983.

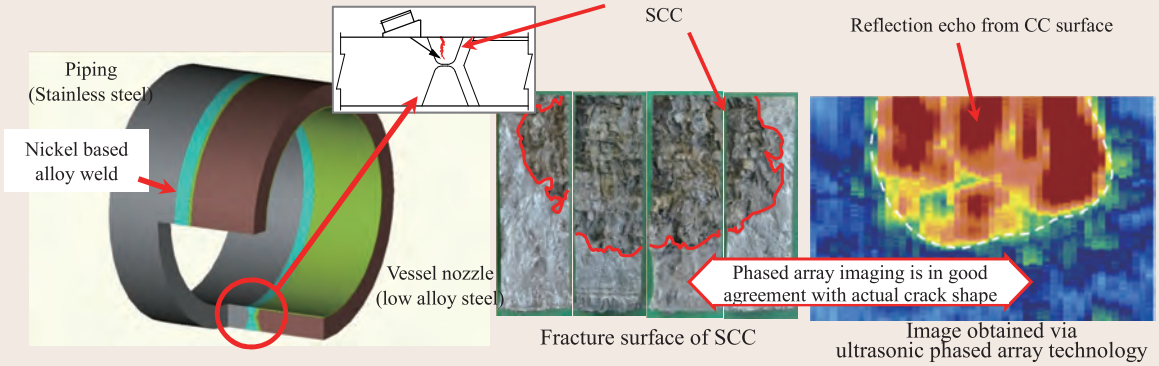


Fig. 1: Comparison between actual shape of SCC and image obtained via ultrasonic test

The identification of a crack tip echo from material noise becomes much easier by using the phased array crack shape imaging technique. This technique is helpful for improving the accuracy and the reliability of crack depth sizing of SCC in DMWs.

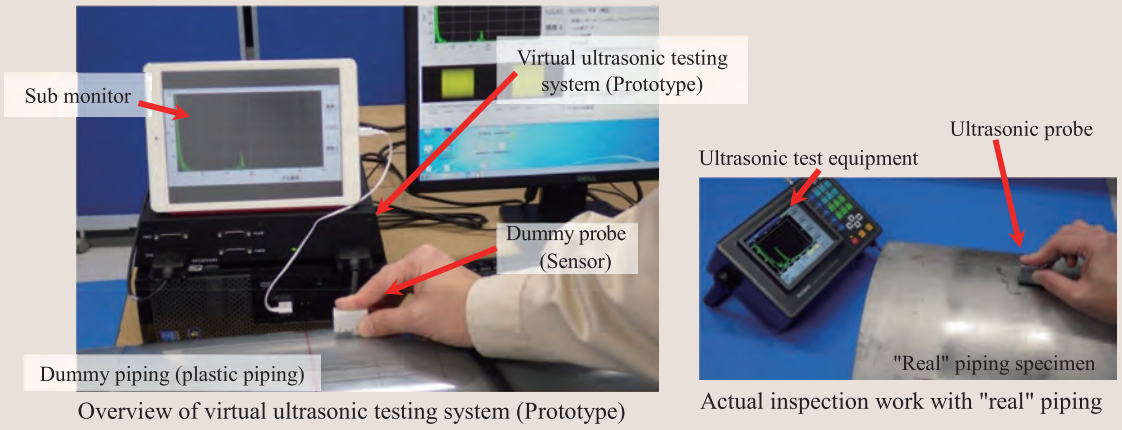


Fig. 2: Virtual ultrasonic testing system (Prototype)

A prototype of a virtual ultrasonic testing system was developed which could display the ultrasonic waveform without time lag depending on the position of a dummy probe, skew angle and contact condition. This system provides the potential for effective training of examination personnel on a specimen without defects, which is similar to training performed on actual specimens. Further, the system can also simulate various cases by editing and modifying waveforms acquired from actual specimens.

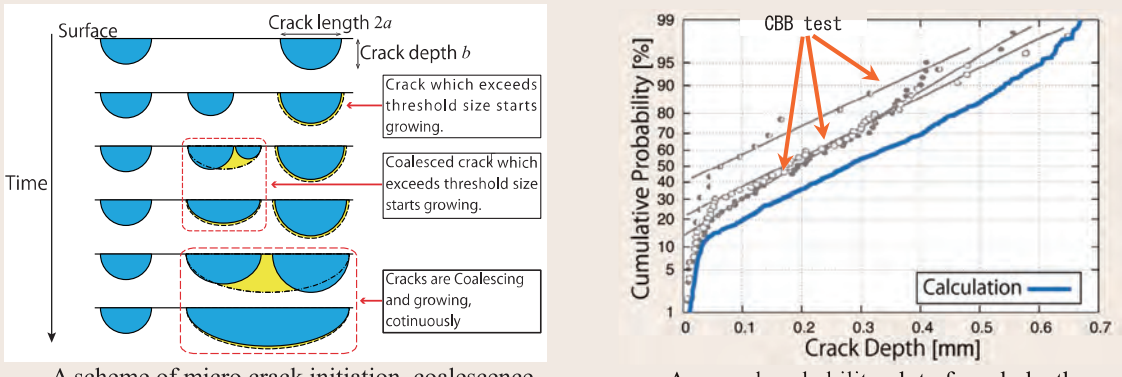


Fig. 3: Modeling for SCC with micro crack coalescence and growth

The simulation adopted a model that randomly initiated micro cracks with constant aspect ratio b/a, which exceed a threshold size, and started growing at a constant growth rate. The calculated distribution well reproduced experimental distributions for sensitized stainless steel described by normal probability distributions with depths over 0.05 mm.

Priority Subjects with Limited Terms — **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*1 damage has occurred in various types of welded joints in the large-diameter high chromium steel (9Cr and 12Cr steel) pipes of 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 steel is required as a preventive measure. In this project, we aim to develop diagnostic techniques for assessing creep damage in girth welds and nozzle stub welds of the high-Cr steel pipes, which are both welds vulnerable to creep damage, and to apply the technologies to the on-site maintenance and operation of facilities.

Main results

1 Development of a method for estimating creep life of 9Cr steel welded joints considering welding conditions

A creep test was carried out at 650°C using 9Cr steel welded joint specimens with different properties, such as the angle of weld groove*2 and rewelding position, to estimate their creep rupture life under given stress conditions. The results indicate that a portion of 9Cr steel welded joints had a creep rupture life up to approximately 1/5 of that of standard joints. A method for estimating the creep rupture life using the angle of weld groove and rewelding position as parameters was also developed and applied to the estimation under the conditions adopted in the above creep test. It was confirmed that the developed method can be used to estimate the creep rupture life of 9Cr steel welded joints, which depends on the welding conditions, with a certain level of accuracy (Fig. 1).

2 Application of a nondestructive inspection technique for 9Cr steel girth welded joints

A bending-internal pressure creep test was carried out up to approximately 6500 hours using a 9Cr steel hot reheat pipe with a girth joint as a specimen. As test conditions, the temperature was 650°C and the ratio of circumferential stress to axial stress was 1:1. When approximately half the test duration (3500 h) passed, the test was ceased to inspect the specimen using phased array ultrasonic testing. As a result, faults considered to be creep damage were detected inside the specimen in the thickness direction (Fig. 2). It was suggested that nondestructive ultrasonic testing is effective for detecting faults inside 9Cr steel pipes with a girth joint in the thickness direction.

3 Proposal for a new index for creep damage, void cluster

The void number density is a typical conventional index for creep damage. However, its values measured in the latter half of the life of specimens were found to vary among individuals who measured the index. It was clarified that this variation was caused by unclear criteria for judging voids at the coalescence and integration stages (Fig. 3) (R14009). To solve this problem, we regarded a bunch of voids adjacent to each other at the crystal grain level as a void cluster and proposed it as a new index for creep damage. When creep damage on a 9Cr steel welded joint was evaluated using the void cluster, there was less variation in the evaluation results in the latter half of the life of the joint among individuals who measured the index (Fig. 4). In addition, a measurement technique based on image processing that adopted the void cluster as a criterion for identifying voids was developed. By applying the technique to the evaluation of creep damage on the 9Cr steel welded joint, a high repeatability of the measurement results was obtained and the measurement processing speed was improved.

*1 A phenomenon in which a material deforms over time when a certain stress is continuously applied to the material.
*2 A groove made on the mother material to be welded.

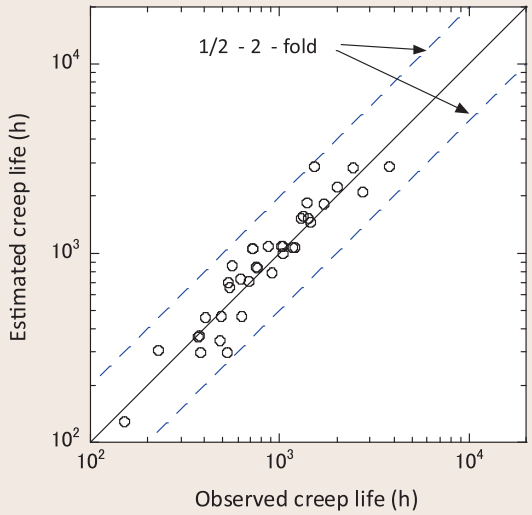


Fig. 1: Estimated results for creep life of 9Cr steel welded joint

The creep rupture life of the 9Cr steel welded joint, which depended on welding conditions, was estimated with a certain level of accuracy by considering the angle of weld groove and rewelding position.

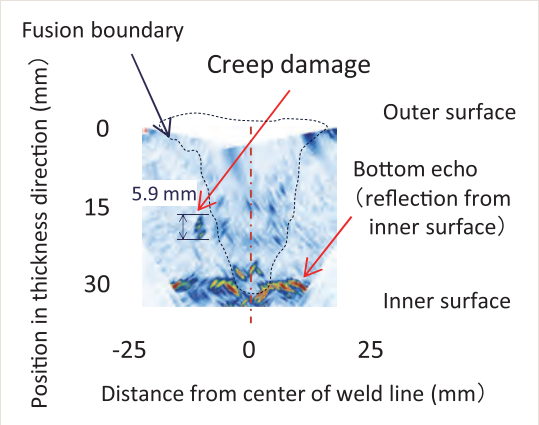


Fig. 2: Results of ultrasonic testing for 9Cr steel girth welded joint

Creep damage inside the joint in the thickness direction was successfully detected.

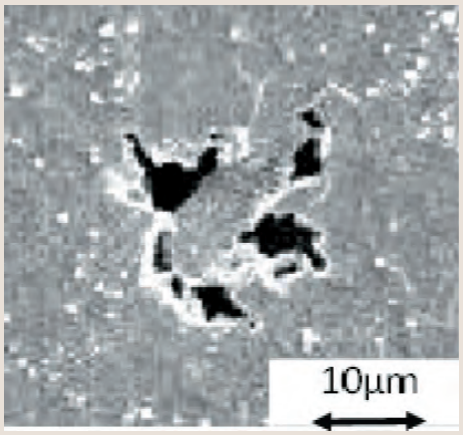


Fig. 3: Voids at coalescence and integration stage (9Cr steel)

Several coalesced and integrated voids are observed in the specimens in the latter half of their life. In the case of the above image, the number of detected voids was varied in the range of 1–8 among individuals who measured the index. Thus, the void number density depended on the individual involved.

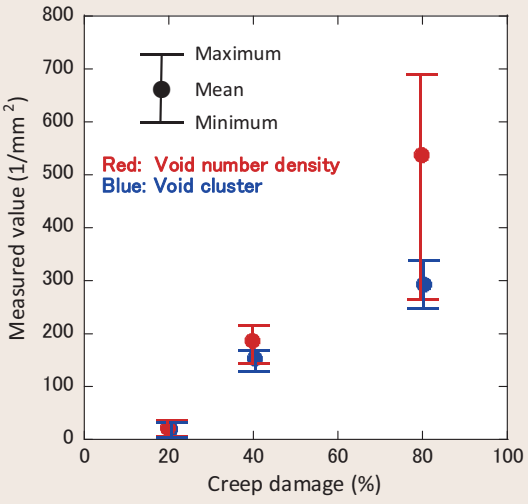


Fig. 4: Proposal of a new index for creep damage

The void cluster was proposed as a new index for creep damage that leads to less variation in measurements than the void number density. The maximum, mean, and minimum in the graph are the values obtained from the results of nine individuals who measured the index.

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

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

Background and Objective

Japan's dependence on thermal power generation and interest in the generation of geothermal power have been increasing with the long-term stoppage of nuclear power plants. In the environmental impact assessment (EIA) of the construction, extension, and replacement of thermal and geothermal power plants, prompt and low-cost assessment is also required as part of national policy. Thermal power plants are suspected to be the emission sources of particles with a diameter of 2.5 μm or less ($PM_{2.5}$). Thus, measures to reduce their emission are likely to be required in the future. The objective of this research is to develop a method and a tool (software) for the simple, rapid, and inexpensive assessment of atmospheric environments. In addition, an assessment method for agents causing secondary air pollution is developed to clarify the impact of their emission sources and to contribute to the formulation of rational measures to reduce the emission of these agents.

Main results

1 Development of an atmospheric EIA support tool for thermal power generation

We have been developing an atmospheric EIA support tool for the simple and rapid assessment of the construction, extension, and replacement of thermal power plants. A function to predict the factors related to sulfur dioxide and dust was added to the tool in consideration of coal-fired power plants. Additionally, a function that can easily compare the ground concentrations measured before and after the replacement and the results of sensitivity analysis under various conditions was added. As a result of adding these functions, the atmospheric EIA support tool almost complies with the dispersion prediction of exhaust gas in the Guidelines for the EIA of Power Plants established by the Ministry of Economy, Trade and Industry (revised in 2007). Furthermore, the support tool enables the evaluation of predictions while complying with the Guideline for Streamlining EIA Methods on Thermal Power Plant Replacements established by the Ministry of the Environment (revised in 2013)*1 (Fig. 1) (V14017).

2 Development of dispersion prediction numerical models for atmospheric EIA of geothermal power generation*2

The research team constructed two types of atmospheric dispersion numerical models, one of which was simplified and one which was detailed*3. For the simplified model, a test calculation of the model considering the effects of reactor buildings and the local geography was carried out and a function to predict the dispersion of white smoke was also incorporated. For the detailed model, it was confirmed that it reproduces the results of wind tunnel experiments reasonably well for a simple geography (Fig. 2).

3 Development of a method for assessing impact of domestic thermal power plants on $PM_{2.5}$ concentration

The research team carried out a simulation of $PM_{2.5}$ concentration over a wide area using the latest publicly available data (FY2005) on the amount of emission of precursors causing air pollution. The team confirmed that the concentrations of the major $PM_{2.5}$ components, except carbon compounds, are reproduced reasonably well. The impact of domestic and overseas emission sources on the $PM_{2.5}$ concentration in Japan was assessed using a tagged tracer method.*4 The results indicated that overseas emission sources account for 47% of the $PM_{2.5}$ concentration observed in Japan and that domestic thermal power plants account for 3% (Fig. 3) (V14005).

*1 Guidelines that specify the rationalization of procedures, such as the shortening of the duration of assessment, when the environmental load can be reduced by the renewal of facilities.
*2 Jointly developed with New Energy and Industrial Technology Development Organization (NEDO).
*3 The simplified model operates on a PC and is applicable to a relatively simple geography, whereas the detailed model considers the effects of a complex geography and buildings and exhibits high accuracy.
*4 A method of calculating the impact by tagging emitted precursors (emission source information) and tracing their behavior.

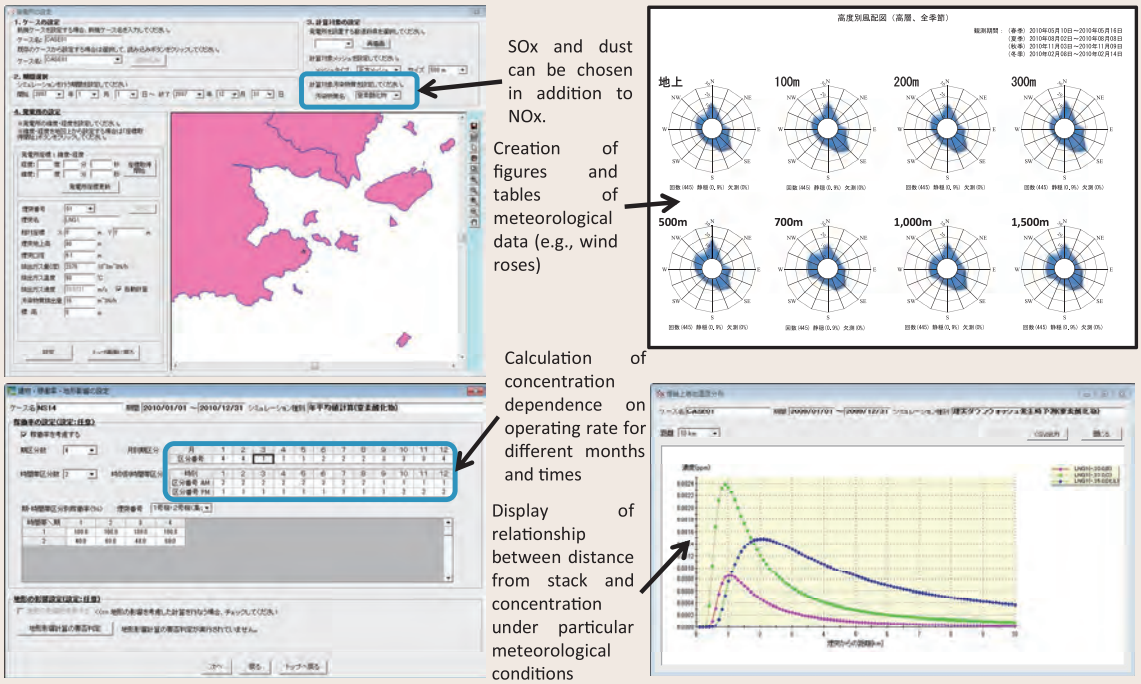
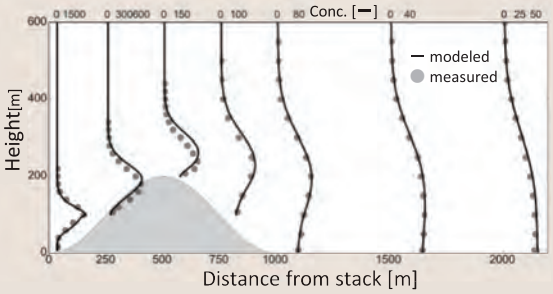


Fig. 1: Main improvements to atmospheric environmental assessment support tool

Upper left: Screen for inputting target point, target period, and specifications of emission gas / Lower left: Screen for inputting operating rate / Upper right: Screen for outputting wind roses for different heights / Lower right: Screen for outputting results calculated under particular meteorological conditions.

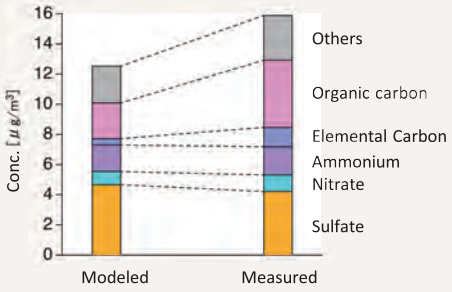
Wind tunnel experiments for three-dimensional hilly geography



Standardized concentration distribution along with leeward distances

Fig. 2: Wind tunnel experiments (upper) and comparison of results obtained by detailed model and wind tunnel experiments (lower)

Wind tunnel experiments were carried out considering the surface roughness of a geographical model and the combined effects of the geography and buildings to obtain data used to verify the numerical model.



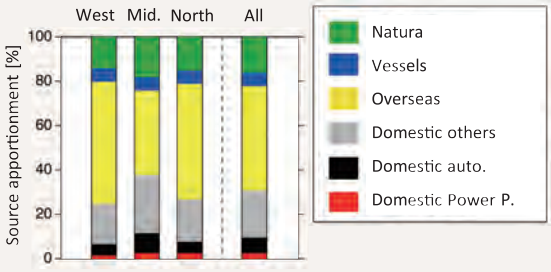


Fig. 3: Modeled and observed $PM_{2.5}$ compositions (upper) and calculated impact of various emission sources on $PM_{2.5}$ (lower)

The calculated results accurately predict the concentrations of sulfate and nitrate emitted from power plants, although the concentration of the carbonaceous compound is lower (upper). The percentage impact of power plants on the $PM_{2.5}$ concentration is smaller than that of other emission sources (lower).

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

Development of Technologies for Increasing Use of Coal Ash

Background and Objective

Since the Great East Japan Earthquake, coal-fired power plants have remained in full operation as base-power generation plants and the annual generation of coal ash is approaching nine million tons. Approximately 65% of the coal ash is recycled by cement companies and used as raw material for cement; however, the demand for coal ash as a cement material is now almost saturated. Thus, other uses of coal ash are being sought. In addition, there are power plants that do not have landfill disposal sites and those with a remaining useful life of only a few years. Therefore, the expansion of coal ash applications is urgently required.

The objective of this research is to promote the use of coal ash as a concrete admixture and in materials used in civil engineering (e.g., artificial ground materials and secondary concrete products). With this objective, quality standards for the above products have been prepared, as the lack of standards will impede the promotion of their use. In addition, technology for stably ensuring the quality and volume of these products has been proposed and developed.

Main results

1 Development of a rapid quantification method for SiO_2 content and its incorporation in JIS

For the quality control of fly ash used for concrete admixture to ensure its stable strength, a SiO_2 analysis method that complies with JIS A6201 is required as the majority of SiO_2 in fly ash reacts with the calcium hydroxide in cement. The conventional analytical method has drawbacks such as a long measurement time of three days and the generation of toxic gas during the test. The research team developed new procedures, in which fly ash is pulverized depending on its properties (Fig. 1), pressed, and subjected to X-ray fluorescent spectrometry to determine the SiO_2 content (N14021). With this method, the results can be obtained within half a day and no toxic gas is generated, contributing to efficient and stable quality control. The achievements of this study were reflected in the revision of JIS A6201 in March 2015.

2 Development of cement-free concrete —Development of fly ash concrete—

A technique for manufacturing concrete without using cement is desirable as the environmental impact of the CO_2 emitted during cement manufacturing is high. The research team has been developing fly ash concrete by steam curing using fly ash and an alkaline aqueous solution. The application of the fly ash concrete to Hume pipes* was examined to utilize its high resistance to sulfuric acid. Regarding the compressive strength (≥50 N/mm^2 required for actual application), which has been an issue to be resolved, it was found that a compressive strength of ≥60 N/mm^2 was obtained by adding a small amount as a powder material and incorporating an improved mixing method, indicating the practical applicability of the fly ash concrete to these pipes (Fig. 2).

3 Development of a rapid method of measuring boron content and amount of eluted fluorine

The consideration of environmental safety is essential for the use of coal ash, for which measurement of the contents and amounts of eluted trace substances will be of fundamental importance. Thus far, the research team has developed a simple and rapid measurement method for chromium, selenium, and arsenic among the trace substances requiring special consideration from the viewpoint of environmental safety (V13023). A rapid measurement method is also required for boron and fluorine, which are similarly considered to be important elements. Thus, the research team has developed a neutron boron gauge that can rapidly determine the content of boron in coal ash in approximately 5 minutes (one-twentieth of the time of conventional methods) using the property of boron that captures thermal neutrons (V14003). In addition, a new test method was developed involving the use of a wet ball mill that can reduce the time required for the elution of fluorine from a sample to one-twelfth of the conventional method (V14004). By combining these techniques, environmentally-safe coal ash can be screened in a short time and the quality of the material for artificial ground containing coal ash as a major ingredient can be effectively controlled during manufacturing (Fig. 3).

* Reinforced-concrete aqueduct used for irrigation water and sewage requiring high strength and acid resistance.

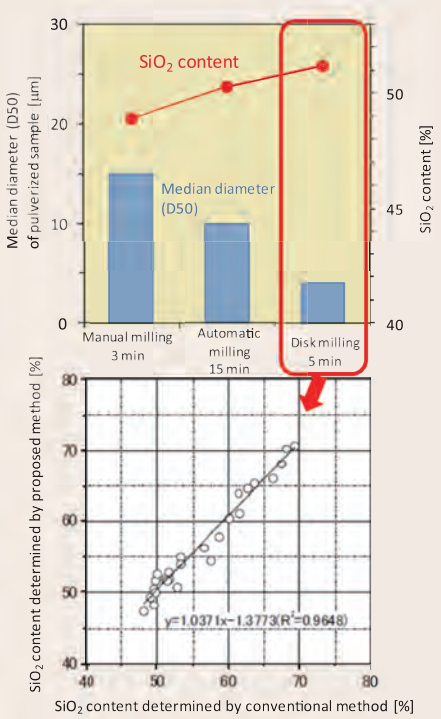


Fig. 2: Effect of pulverization method on analyzed SiO_2 content (upper) and correlation between the SiO_2 contents determined by proposed and conventional methods (lower)

Complete pulverization of a sample in a disk mill followed by pressure forming is effective for precisely measuring the content of SiO_2 in fly ash by X-ray fluorescent spectrometry.

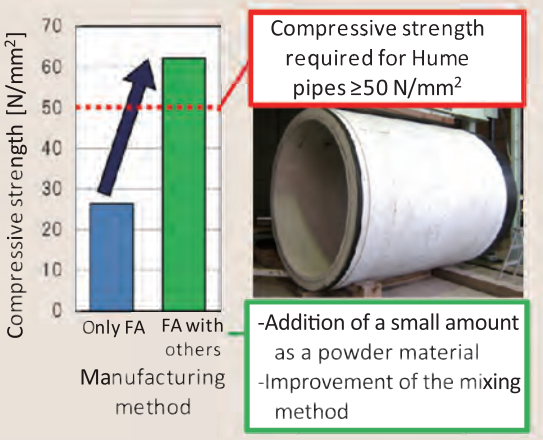


Fig. 2: Improvement of fly ash concrete strength

The maximum compressive strength of the fly ash concrete, manufactured by the method used until last fiscal year, was approximately 27 N/mm² (left bar in the figure). By adding a small amount as a powder material, incorporating an improved mixing method, and reducing the water-powder ratio, * the research team demonstrated the possibility of manufacturing fly ash concrete with a compressive strength of ≥60 N/mm² and a flexural strength of ≥7 N/mm².

* Water-powder ratio: (mass of water)/(mass of powder materials) × 100 (%)

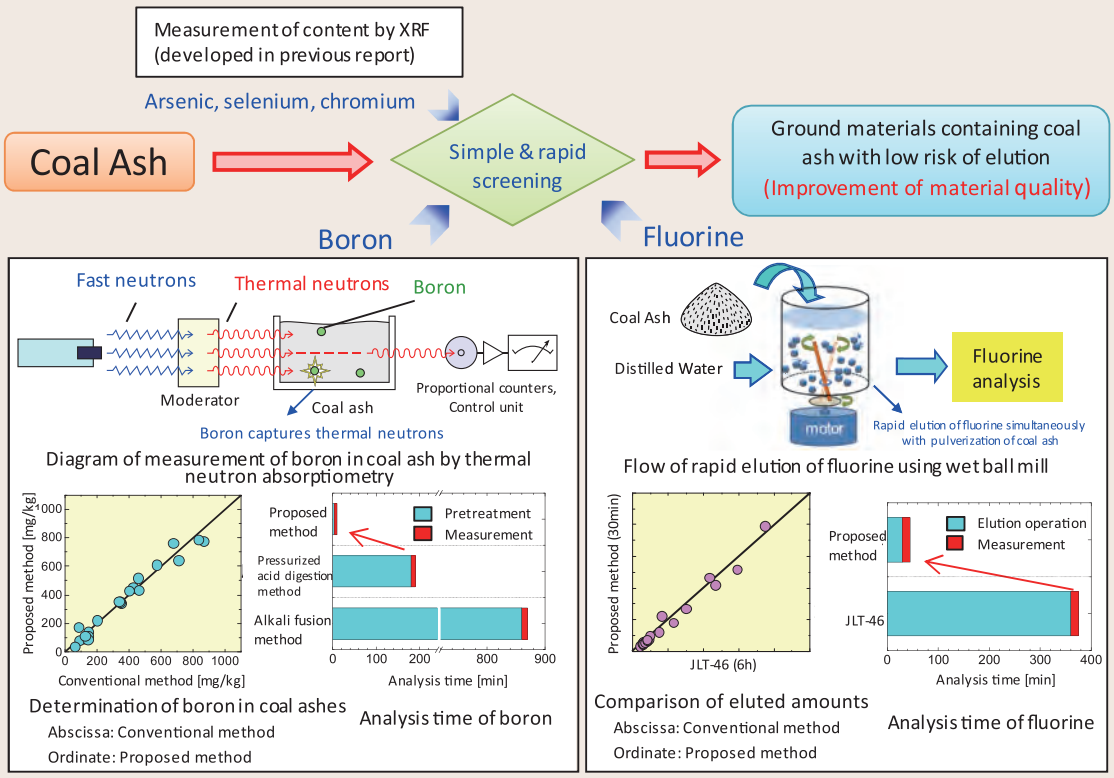


Fig. 3: Simple and rapid measurement method for content of boron in coal ash by thermal neutron absorptiometry and amount of eluted fluorine using wet ball mill

Using thermal neutrons and a wet ball mill, the boron content and the amount of eluted fluorine can be determined in a shorter time with a precision comparable to that of the conventional method.

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

Development of Efficient Impact Assessment Methods for Ecosystems

Background and Objective

According to the amendment of the Environmental Impact Assessment Law in 2011, the assessment of biodiversity must be included in the Environmental Impact Statement at the planning stage of construction of new power plants and expansion of existing plants, and the results of environmental conservation measures must be published. In addition, wind-power generation was added as a new target project regulated by the said law. Government-level discussions regarding the necessity of biodiversity offsets*1 and the assessment of environmental impact of power plants on marine ecosystems have begun, increasing the necessity for technological developments related to the introduction of new regulations and systems.

The target of this research is the development of technologies related to biodiversity assessment and conservation, which enable the smooth construction, renewal, and operation of power plants.

Main results

1 Development of a three-dimensional coordinate system for flying birds

In the environmental impact assessment of the construction of wind power plants, the frequency of birds flying at the height corresponding to wind turbines should be clarified to predict the collision frequency of birds with wind turbines. Conventionally, flying birds were visually observed; however, this requires considerable effort and the error is large. To efficiently obtain data on the flight heights of flying birds, the research team developed a three-dimensional coordinate system for obtaining the three-dimensional positions of flying birds using images simultaneously recorded by two cameras. The precise determination of the frequency of birds flying at the height corresponding to the swept area of wind turbines was confirmed to be possible from the results of long-term observation of flying birds using the system and the three-dimensional coordinates of flying birds (Fig. 1). Future goals are to develop a transportable system and to carry out verification in various environments, with the aim of developing a versatile method that can be applied to environmental impact assessment.

2 Development of a method for predicting impact to population of principal plant species*2 in order to determine the necessity of conservation transplantation

In environmental impact assessment, the necessity of conservation transplantation of principal plant species depends on the degree of impact and mitigation measures to focal populations such as relocation and/or minimization of construction areas. The research team developed a method of efficiently and quantitatively predicting the degree of impact mitigation to the plant population using minimal parameters (e.g., survival rate and reproductive rate estimated from the distribution of the plant) and alternative draft layouts of construction areas (Fig. 2). The method will be verified and further improved using data on actual sites, so as to be employed in actual environmental impact assessments for the reduction of uncertainty and the cost associated with conservation transplantation.

3 Development of a technology for predicting standing biomass of seagrass bed during the growing season

Among marine ecosystems, the seaweed and seagrass bed ecosystem plays an important role as a location of high biological production and a habitat of various living organisms. To estimate standing seaweed and seagrass biomass during the growing season, which is necessary in environmental impact assessment, a submersible survey involving considerable time and cost is required. The research team developed a simple numerical model for predicting the standing biomass using publicly available data (e.g. solar irradiance, sea temperature, and transparency) released by public institutions [1]. In FY2014, the research team developed a model for seagrass beds formed on a sandy sea bottom in Japan and validated the model with observed data (Fig. 3). The model enables estimation of the standing biomass of seagrass in various regions of Japan, and contributes to rapid and low-cost assessment.

*1 When the impact to ecosystems in developed areas cannot be mitigated on site, such residual impact to the ecosystems can be mitigated by creating and/or maintaining similar ecosystems at other sites.
*2 Principal species refer to the species listed in national and municipal laws and regulations as being critically endangered or easily affected by changes in the environment.

[1] M. Honda, *Algae*, 62:143–151, 2014.

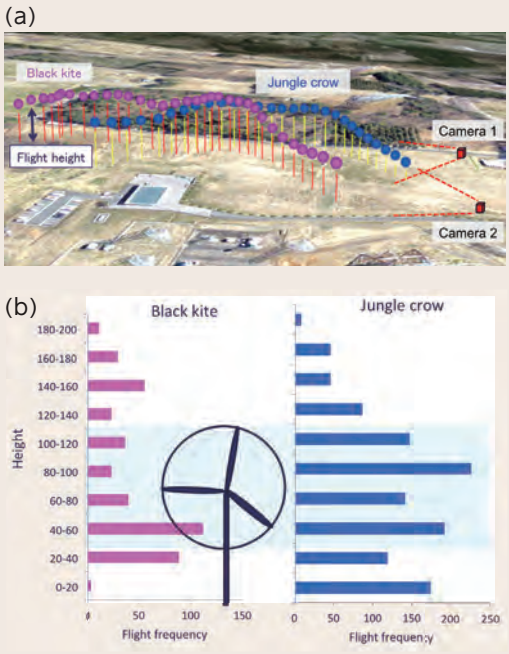


Fig. 1: Quantification of the flight heights of flying birds using a three-dimensional coordinate system

Examples of positions of flying birds represented three-dimensionally using images simultaneously recorded by two cameras (pink and blue circles represent the positions of a black kite and a jungle crow, respectively) (a). Distribution of flight height of black kite and jungle crow quantified using images recorded over 50 h (b). Both the black kite and the jungle crow fly at heights corresponding to those of the rotary plane of wind turbines with a frequency of ≥40%. The system enables us to efficiently obtain precise flying data required to estimate the collision frequency of these bird species with wind turbines.

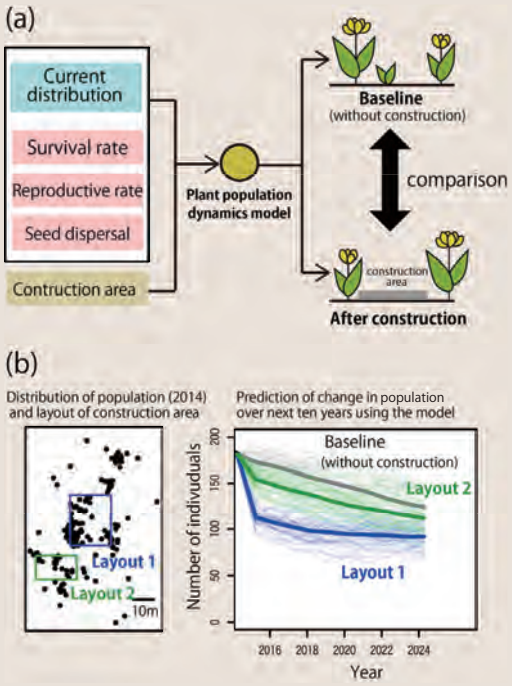


Fig. 2: Prediction of change in population using a plant population dynamic model

The change in the population of principal plant species is predicted using parameters (e.g., survival rate, reproductive rate, and seed dispersal distance), the current distribution of the plant, and draft layouts of construction areas (a). The impacts of two alternative draft layouts on the population of the golden orchid (a principal species) were compared with that of the baseline (without construction). The results indicate that the impact of draft layout 2 on the golden orchid is smaller than that of draft layout 1 (b).

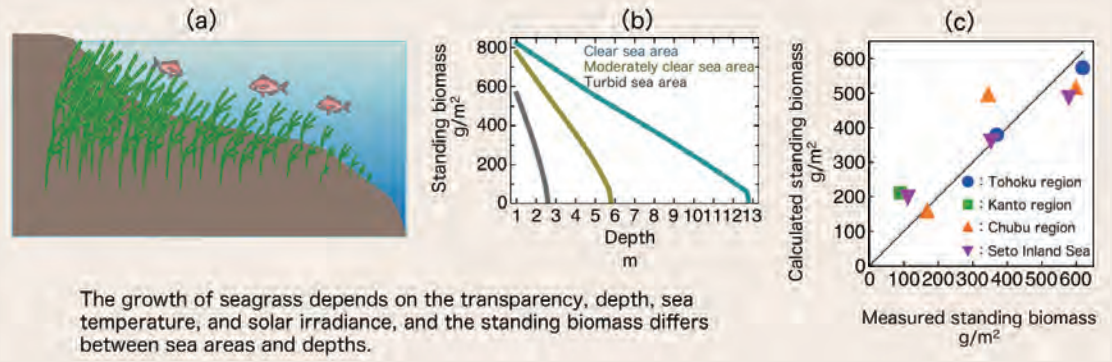


Fig. 3: Numerical model for predicting the growth of seaweed

In the model, the standing biomass of seagrass during the growing season at different depths of water is predicted using environmental data, such as solar irradiance, sea temperature, and the transparency of each sea area (a, b). For the seagrass beds in the Tohoku, Kanto, Chubu regions, and Seto Inland Sea, where detailed ecological examinations have been carried out by universities and fisheries research institutes, estimated values of the standing biomass from the numerical model with the environmental dataset were consistent with reported values. The results confirmed that the numerical model can accurately predict the standing biomass (c).

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

Synthesis System of Numerical Analysis for Current and Sediments in River and Reservoirs

Background and Objective

The proper maintenance and operation of hydropower facilities owned by electric power companies are important in terms of provisions for stable electric power supply and renewable energy utilization. In recent years, forests along 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 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 Estimation of sediment yield from upstream mountains

We measured sediment yield within forested slopes in a Japanese cypress and a nearby Japanese cedar with no shrubs. The sediment yield increased as the amount of precipitation in both slopes increased, and that in Japanese cypress with poor forest floor cover was approximately one order higher than in Japanese cedar (Fig. 1 top). Forest height, canopy interception rate, understory interception rate and ground interception rate was measured by laser profiler data. We prepared a map of raindrops kinetic energy, that control rain-drop erosion of soil, to estimate the sediment production from upstream mountains (Fig. 1 bottom).

2 Modified risk evaluation method of slope failure for slopes in a widespread area

A risk evaluation method of slope failure was modified to reduce input parameters which included an inclination and length of a slope, a depth of bedrock and a rainfall pattern assuming that hydraulic properties and mechanical properties were similar for the same geological unit (Fig. 2). The method was also modified to represent a water collection structure, a surface runoff, an existence of a forest road and a water level variation in a downward river/pond which could affect infiltration phenomena (N14016). The modification made it possible to enhance the prediction accuracy of the method and to create a hazard map of slopes in a widespread area. Estimation of the amount of sediment using this method enables an evaluation of sediment increases caused by abnormally heavy rain.

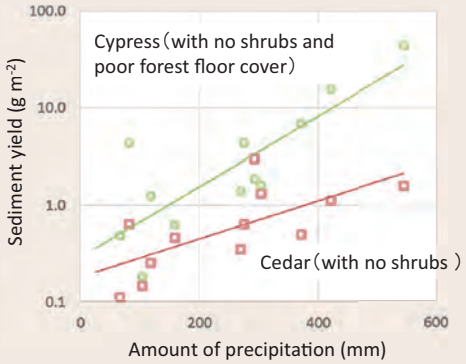
3 Wash-load and turbidity real-time observation using a river environmental monitoring system with a mobile communication device

A real-time river environmental monitoring station was constructed in five points between the immediate-downstream of the dam planned for sluicing operation and river mouth and one point in the tributary. The system sends the information of the river environment (i.e. water quality, turbidity and water level) every thirty minutes by mobile communication device. In addition, we are able to command an auto sampler in this system to collect river water at our discretion. Turbidity and wash-load in water samples in five events with a seasonal rain front and seven events with typhoons were analyzed. Sediment diameter distribution changed depending on the merging tributary. The tributary has a smaller catchment area (63.2 km^2) than mainstream (884.1 km^2), nevertheless the sediment supply from the tributary is important to determine the quality of the suspended sediment composition in the river before sluicing operation.

4 Synthesis system of numerical analysis for flood and sediment transportation

A synthesis system of numerical analysis for flood and sediment transportation was developed in order to estimate flow condition and sediment movement in floods from the upper reaches of a river to its mouth (Fig. 3). The system was applied to a river under the operation of cascade dams to facilitate sediment sluicing. The quantitative impact on deposition and scoring of river beds, as well as the water levels of rivers and reservoirs were estimated for the largest recorded flood. The system may be applied to flood risk analysis and river environmental assessment of dam basins.

* Wash-load is fine sediment under 100-200 μm.



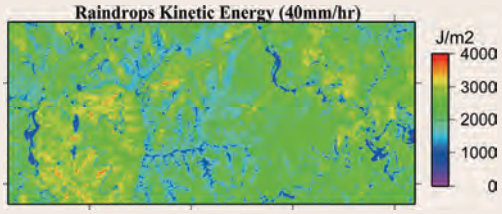


Fig. 1: Technological development for estimation of sediment yield from upstream mountains

The top half of Fig. 1 indicates the relationships between the sediment yield and amount of precipitation. The bottom half shows the raindrop energy distribution that triggers sediment production.

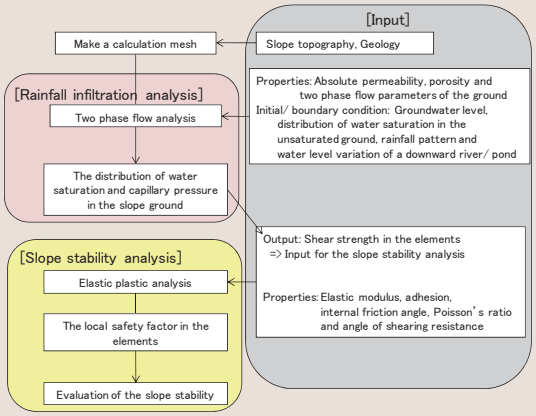


Fig. 2: Calculation flow diagram of the risk evaluation method of slope failure

The distribution of water saturation and capillary pressure in a slope is calculated by a rainfall infiltration analysis with a rainfall pattern. The modification was conducted in FY 2014 to represent a water collection structure, a water level variation in a downward river/ pond and an influent rainfall from a forest road. A local safety factor is calculated by using the water saturation and the capillary pressure varying from hour to hour and a risk of the slope failure is evaluated.

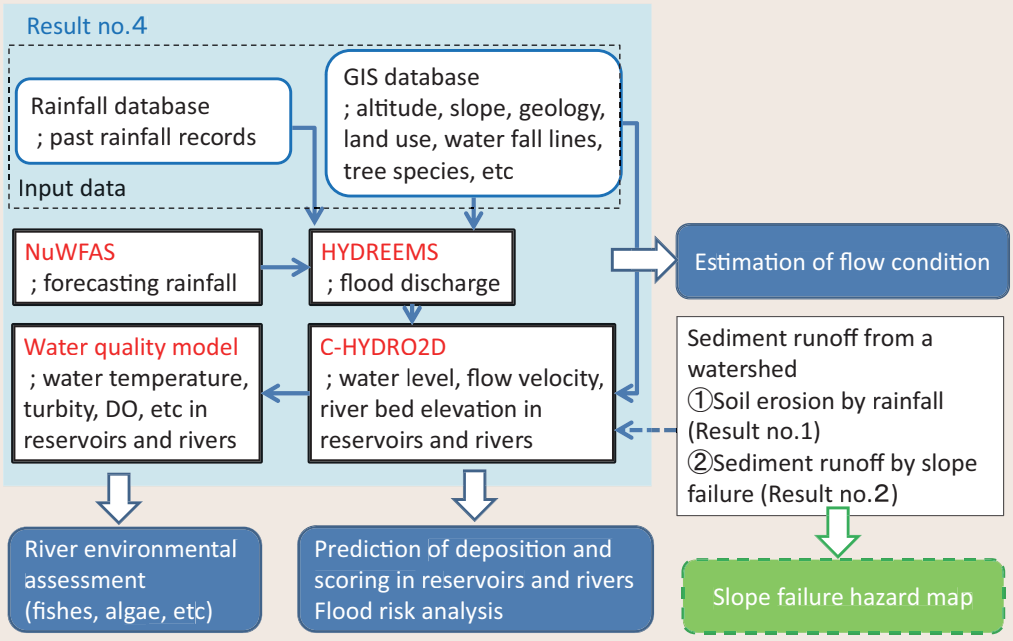


Fig. 3: Flow chart of the synthesis system of numerical analysis for flood and sediment

The system with the NuWFAS, HYDREEMS, C-HYDRO-2D and water quality model predicted future river bed and water quality. Past rainfall records or the predicted rainfall using the NuWFAS were used. HYDREEMS and C-HYDRO-2D use GIS data and can easily be adapted to all areas.

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

Japan's electric power transmission and distribution facilities, which have been installed in large quantities during the high growth period and other specific periods, are aging. As such, their renewal is necessary in the near future. It is important to establish rational operation and maintenance techniques by considering cost effectiveness and to realize leveling of repairing and replacement.
In this research subject, sophisticated diagnostic technologies, which are necessary for this purpose, are developed, and asset management support tools (PC programs) considering their operational information and reliability are provided.

Main results

1 Development of diagnostic technology of oil-immersed power transformers

CRIEPI has been developing a diagnosis method for the abnormality of windings in oil-immersed power transformers such as deformation due to internal electromagnetic force based on Frequency Response Analysis (FRA). FRA had been applied to 64 oil-immersed power transformers, and transformers which have demonstrated abnormality were dismantled. Based on this investigation, diagnosis criteria in emergency situations and in routine inspections are proposed (Table 1). In emergency situations, such as invasion lightning surges, it is important to diagnose heavy deformation of winding and turn short. Diagnosis criteria are proposed and are applicable without past measured data. In detail diagnosis during routine inspection, slight displacement of winding due to aging of press board*1 can be diagnosed which cannot be diagnosed using the conventional method (Fig. 1) (H14010).

2 Development of diagnostic technology of oil-filled cable*2

Recently, it was reported that traces of partial discharges (PDs) were found in oil-impregnated insulation papers of oil-filled cables, although dissolved gases due to PDs were not detected by the dissolved gas analysis of insulation oil. So, it has been pointed out that the degradation of oil-filled cable can progress due to PDs in small voids near inner conductor, ultimately resulting in cable malfunction. In order to clarify the degradation progress of oil-filled cable due to PDs, PD characteristics from their inception to breakdown were investigated by using a cable insulation model. The insulation model has coaxial cylindrical structure which is close to that of oil-filled cable system, and its oil pressure was controlled by the oil pressure control system (Fig. 2a). As a result, PDs continued even when minimum allowable oil pressure was applied to the oil gap defect, and a breakdown occurred in the model after a certain amount of lead time from inception of PDs (Fig. 2b). This result suggests that we can detect the degradation progress by measuring PDs in the oil-filled cables in operation (H14011).

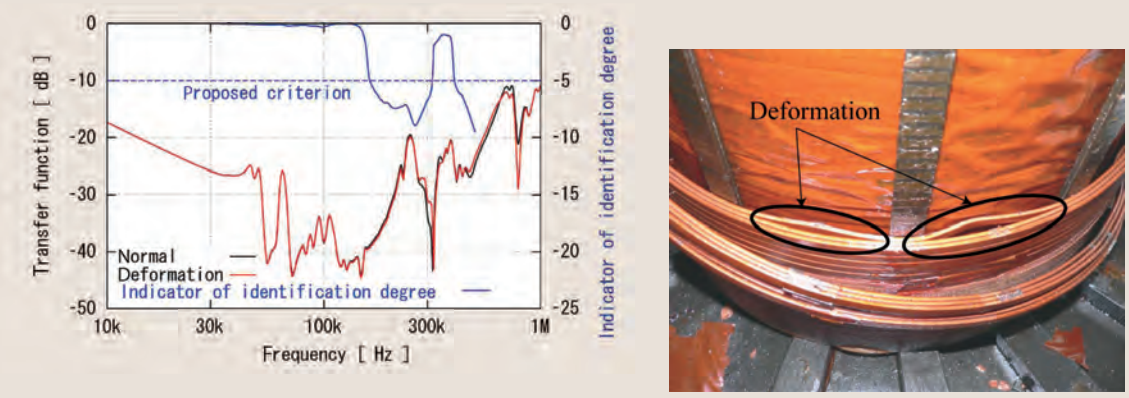
3 Development of asset management support programs and proposal of hierarchical asset management

The asset management technique is being examined to rationalize maintenance strategies of electric power equipment. In Japan, high level reliability in electric power supply is expected, and low failure risk equipment has been operated with preventive maintenance. Therefore, not only statistical failure loss but also maintenance cost in normal operation should be evaluated. CRIEPI has defined an asset management support technique to assure accuracy of input data and objectiveness of the evaluation process in asset management, developed support programs for several kinds of equipment, and proposed the concept of hierarchical asset management, which can carry out evaluation corresponding to available data quality (H09). The asset management support technique is expected to be utilized for rational maintenance of aged equipment.

*1 Cellulose-based material constructed of several layers (plies) of paper compressed using a combination of heat and pressure.
*2 Cables that are electrically insulated by insulation papers and oil. Their oil pressure is kept higher than atmospheric pressure by feeding oil from outside to suppress the generation of voids and intrusion of air or moisture.

Table 1: Proposed criteria for diagnosis of abnormality of transformer winding

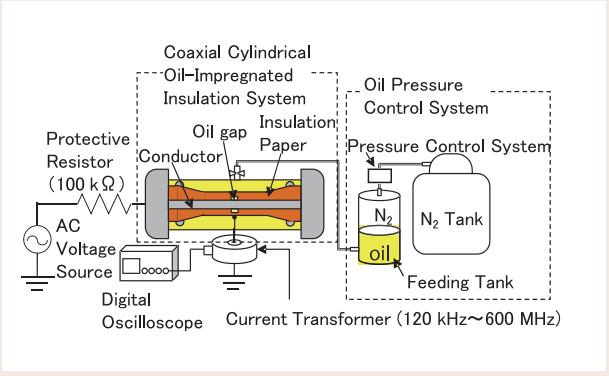
Situation	Targeted abnormality	Diagnosis method
Urgent diagnosis	Heavy deformation	Focus on difference of transfer function at 1kHz compared with that of other phases.
	Turn short	Focus on difference of lowest resonant frequency compared with that of other phases.
Detailed diagnosis	Slight deformation or displacement	Indicator of identification degree of transfer function is compared with a threshold.



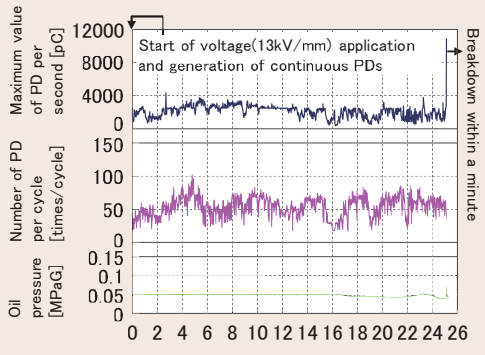
(a) Deformed winding and indicator of their identification degree (b) Transfer functions of power transformer

Fig. 1: Example of diagnosis of transformer whose winding is forcibly deformed

In FRA., winding abnormality is detected by detecting change of transfer function compared with that measured when the transformer was normal. An indicator of identification degree of two transfer functions and diagnosis criteriion of abnormality of winding using the indicator are proposed.



(a) Coaxial cylindrical oil-impregnated insulation model and experimental equipment



(b) Transition of partial discharge characteristics from inception of continuous PDs to breakdown

Fig. 2: Overview of PD measurement of oil-impregnated insulation mode

PDs occurred at oil pressure higher than atmospheric pressure and at the assumed oil gap of coaxial cylindrical electrodes which were insulated by insulation papers and oil as shown in (a). PDs were measured by a high frequency current transformer and a digital oscilloscope. As shown in (b), a large number of PDs continued and finally a breakdown occurred. Also, a large number of PDs with larger charge magnitude occurred and continued for some time before breakdown. This change in PD characteristics may be indicative of breakdown.

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

Development of Soundness Assessment Techniques for Aged Overhead Transmission Steel Towers

Background and Objective

Overhead transmission steel towers constructed during Japan's high economic growth (almost two full decades beginning from 1954) are aging rapidly, giving rise to a need for the standardization of their repair and rebuild, which must be performed with efficiency. Meanwhile, in the 2011 Tohoku Earthquake, larger accelerations than those of the 1995 Southern Hyogo prefecture earthquake were observed, therefore, it is also necessary to gain an understanding of the 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 aim to clarify the seismic margin of steel towers considering elastic-plastic behavior against high level earthquake ground motion.

Main results

1 Development of a rate estimation and inspection method for corrosion inside steel pipe

The validity of ACM sensors for evaluating corrosion rate was demonstrated. The distribution of corrosion rate inside steel pipe acquired by ACM sensors showed good agreement with corrosion loss distribution measured on a cross-section of the steel pipe (Fig. 1) (Q14004). In order to estimate the corrosion distribution, a sea salt deposition evaluation method utilizing CFD was developed. The correspondence of calculated sea salt value and measured sea salt value on exposed pipe was verified. Regarding inspection, corrosion loss of the internal pipe was detected by the magnetostrictive sensor technology for long-range guided wave testing (Fig. 2) (Q14003). An accelerated corrosion test method, dry and wet acceleration, was employed for further investigation of internal pipe corrosion. Validity of the method was demonstrated by several tests.

2 Development of corrosive environment maps and a corrosion rate function

For quantitative evaluation of corrosion factors in coastal and inland areas, observations of corrosive environments were carried out continuously at a coastal testing field (Yokosuka city, Kanagawa prefecture) and an existing transmission tower (Narita city, Chiba prefecture) (Fig. 3). Also, maps of corrosive environment factors such as airborne sea salt, temperature and humidity (in almost the whole of Japan) were made by using the sea salt transport evaluation system, NuWiCC-ST, and ultra-high resolution weather reproduction data from the past 53 years, which was reproduced by the weather prediction and analysis system, NuWFAS (Fig. 4). In addition, in order to develop appropriate maintenance plans for transmission towers including inspection prioritization, dose-response functions defined by ISO9223 and ISO994 were improved based on existing atmospheric exposure test results. As a result, a Japanese version of corrosion rate functions was proposed. The proposed functions enable us to approximately estimate the corrosion amount of transmission towers installed in various corrosive environments.

3 Construction and trial of a database system for aging steel towers

A database for the corrosion risk evaluation of transmission steel towers managed by all electric power companies was constructed. The database includes maintenance history data, weather meteorological observation records, survey reports associated with removal corrosion materials, estimated corrosion values using the proposed corrosion rate evaluation models, and maps associated with corrosion environmental factors. In addition, the functions of the developed database system include data searching, data downloading, and data display in the form of an open street map. Currently, the developed system is being trialed by all power companies.

4 Development of a nonlinear analysis model for a transmission tower members' junction in consideration of bolt slippage

In the soundness confirmation of transmission steel towers, which have suffered differential displacements among the main leg members, high-level earthquakes or heavy winds, a more realistic evaluation in consideration of bolt slippage of a transmission tower members' junction is required. In order to contribute to this study, we developed a structural analysis method for the bolt slippage in terms of double nodes and nonlinear spring elements between the nodes, which models the tower members' junction. By using this method, we have made it possible to conduct a highly-precise soundness evaluation which takes the stress redistribution caused by the bolt slippage into account (Fig. 5).

* Sensor for measuring the corrosion rate of metal in a given environment.

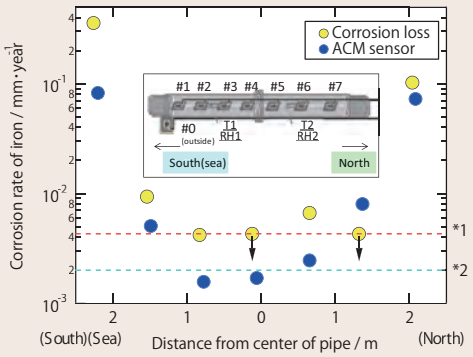


Fig. 1: Distribution of corrosion rate inside steel pipe

Corrosion rate acquired by the cross sectional observation of pipe wall thickness showed similar distribution as the result of experiment using ACM sensors.

*1: lower limit of corrosion rate based on the cross sectional observation.
*2: lower limit of corrosion rate which can be calculated from the output of ACM sensor.

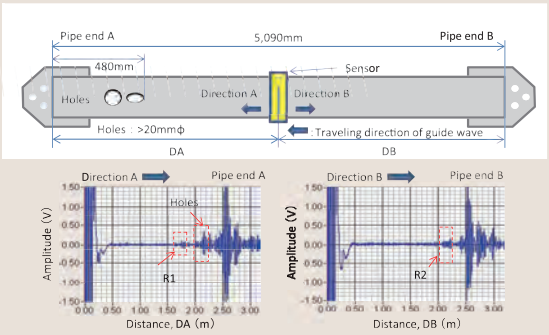


Fig. 2: Guide wave inspection of internal material losses

Reflectors at locations R1 and R2 of an externally painted steel pipe removed from a transmission tower except for pipe ends and holes were observed by transmitting guided waves in directions A and B. Internal material losses at different degrees were detected at the location by ultrasonic testing.

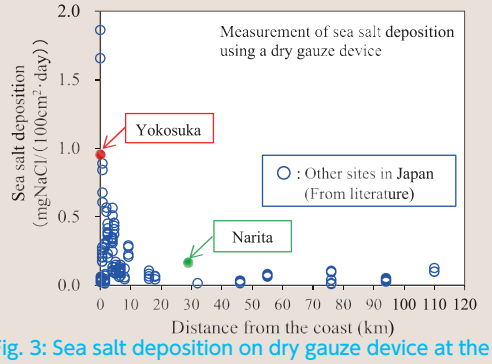


Fig. 3: Sea salt deposition on dry gauze device at the monitoring stations

Sea salt deposition was measured by using dry gauze device at Yokosuka and Narita sites. The measured depositions were compared with those at other Japanese sites previously published in literature. Reduction in the sea salt deposition with distance from the coast is clearly represented.

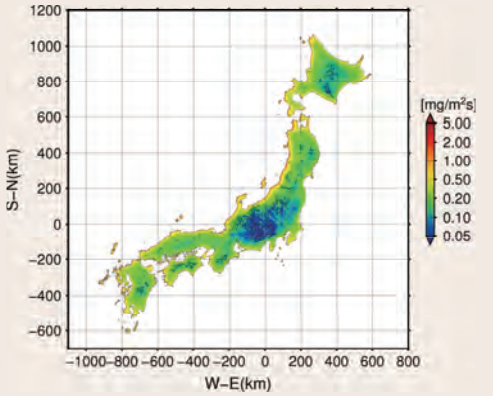


Fig. 4: A map of the annual mean amount of airborne sea salt

A map of the annual mean amount of air borne sea salt with a spatial resolution of 1 km at a ground height of 20 m is shown here. The NuWiCC-ST was used for making it with the frequency distribution data of offshore wind in the past 53 years, which was reproduced by NuWFAS.

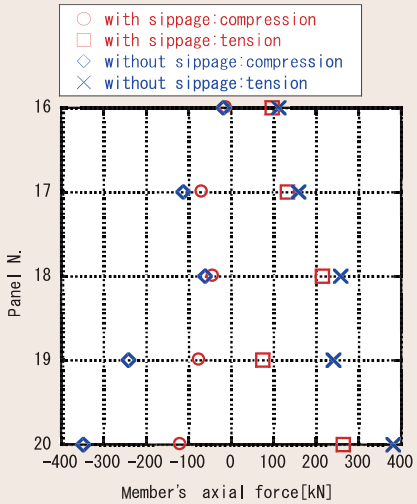


Fig. 5: Wind response analysis in consideration of bolt slippage

In regards to a 500 kV transmission steel tower (69.5 m in height, all 20 panels), we compared the main member's axial forces for two cases in which bolt slippage is either considered or ignored. Fig. 5 shows the maximum and minimum axial forces that occurred under the action of the wind load from the 16th to 20th (bottom layer) panels. The values with slippage are smaller, and it was suggested that estimation could be excessive if bolt slippage was not considered.

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 coal is sought to diversify fuel types in pulverized coal-fired power plants. In the diversification of fuel types, the countermeasures against sulfide corrosion of boiler tubes and the control technologies of trace elements such as Hg, B, Se, are also important issues.

In this research subject, the guideline for the suitable operating conditions of a mill and a burner, the blending method of coals, etc. will be formulated to use low HGI coal*1 (low grindability coal) in existing pulverized coal-fired power plants. In regards to sulfide corrosion, countermeasures for the tube will be developed. Control technologies of trace elements in flue gas and in waste water treatment processes are also under development. These technologies contribute to the diversification of fuel types in pulverized coal-fired power plants.

Main results

1 Clarification of roller mill operating condition for the blend of low HGI coal and bituminous coal

The combustion test of low HGI coal mined in the Surat Basin in Australia demonstrated high combustion efficiency and low NOx emission. Under ordinary grinding conditions in a roller mill (weight ratio of pulverized coal passing through 75 μm mesh of the sieve: 70-80%), the low HGI coal required high grinding power due to low grindability. As the fuel ratio*2 of the blended coal composed of bituminous and low HGI coals decreased, grinding power increased and the maximum blending ratio of low HGI coal under the permissible power of the roller mill decreased. When the rotation speed of separator in the roller mill was decreased to make coal particles coarse, the weight ratio of pulverized coal passing through 75 μm mesh of the sieve decreased to 30-50%, and grinding power decreased. Then, it was discovered a high blending ratio of low HGI coal could be obtained, though the blended bituminous coal of low fuel ratio had low grindability.

Furthermore, when low HGI coal was blended with the bituminous coal of a higher fuel ratio, the combustion efficiency improved significantly.

Based on grinding and combustion characteristics of the low HGI coal and the coal blends, a guideline for the suitable operating conditions to use low HGI coal in pulverized coal-fired power plants was formulated (Fig. 1).

2 Verification of sulfide corrosion-resistant coating in actual boilers

A sulfide corrosion-resistant coating was developed in order to economically and easily prevent sulfide corrosion on boiler tubes. The developed coating could be fabricated in a manner similar to spraying paint. To evaluate the operational durability of the coating, verification tests were performed through the application in six actual coal-fired boilers and two actual oil-fired boilers. Through verification testing in actual boilers, it was found that the coating suppressed corrosion to less than one-fourth of the corrosion on uncoated tubes as shown in Figure 2. Also, the coating was found to maintain a good condition for a minimum of 2 years (M04). CRIEPI has licenses this coating technology to a company.

*1 HGI (Hardgrove Grindability Index) is an evaluating factor for the grindability of coal. As HGI decreases, it becomes harder to grind. The HGI of bituminous coal utilized in Japanese power stations ranges from 40 to 70. The HGI of low HGI coal in this study is below 40.

*2 Fuel ratio is the mass ratio of content of fixed carbon to volatile matter in coal. As fuel ratio decreases, combustion efficiency increases and grinding power increases.

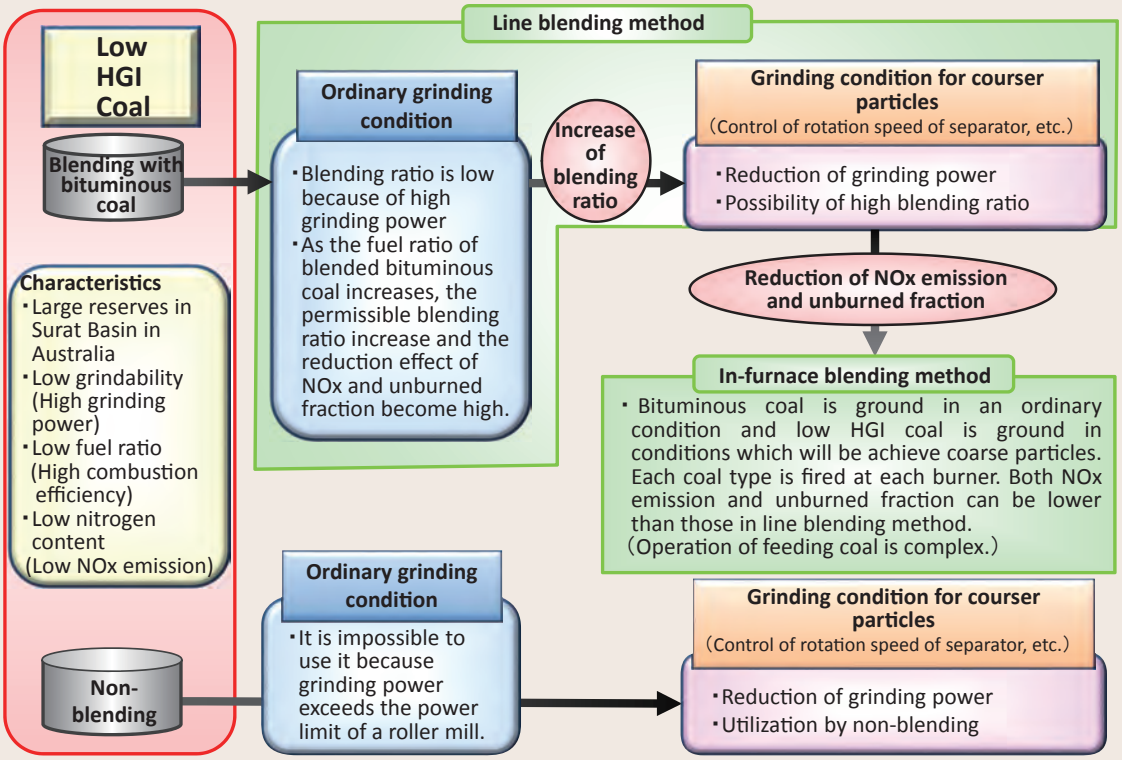


Fig. 1: Suitable operating condition for low HGI coal in pulverized coal-fired plants

Suitable operating conditions for low HGI coal under blending and non-blending conditions are clarified.
Line blending method: Two types of coals are blended before the roller mill and are fired at the same blending ratio for each burner.
In-furnace blending method: Two types of coals are ground at each mill and are fired at each burner.

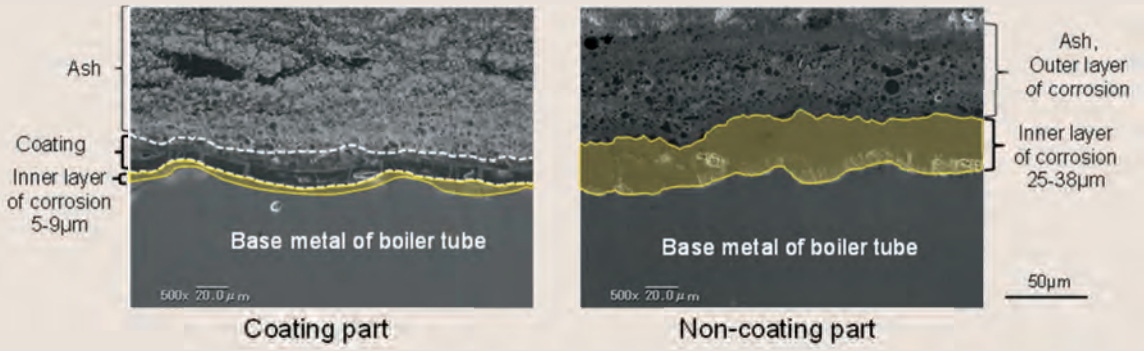


Fig. 2: Cross-sectional SEM image of the coated and uncoated parts on the coal-fired boiler tube

The developed coating has a four-layered structure comprising thin films of (1) a SiO_2 layer, (2) a TiO_2 layer, (3) an Al_2O_3-based layer, and (4) a TiO_2 layer. This coating process can be applied to a large area in a short period. When the coating area is 100 m^2, the work takes 3 days and total spraying time is only 7 hours. CRIEPI coating reduced corrosion to 25% or less compared with an uncoated part. It was found that CRIEPI coating on boiler tubes is exceptionally durable and continues to be effective for more than 2 years in actual power plants.

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

Improvement of Utilization Technology for Low-Grade Energy Resources

Background and Objective

As one of the carbon dioxide emission reduction measures for coal-fired power plants, co-combustion of biomass has been promoted in Japan, but the mixing ratio of biomass remains at a few percent due to the difficulty of biomass pulverizing compared to coal. In this project, we aim to develop a carbonization technology of biomass, the evaluation technology and standardization of carbonized biomass fuel used in coal-fired power plants. These are useful to improve the mixing ratio of biomass in co-combustion and to reduce the carbon dioxide emissions from coal-fired power plants.

Main results

1 Development of carbonization technology and estimation technology

Carbonized biomass fuel for commercial use is required to have a stable fuel property, such as heating value, fixed carbon, and fuel ratio*1. The property of carbonized biomass varies according to the carbonizer operation conditions such as feed rate of raw biomass, carbonization temperature and residence time. To maintain the property stably, continuous measurements must be made of the carbonized biomass and the measured values must be fed back into the carbonizer operation conditions. Carbonization tests were carried out on woody biomass using a demonstration scale carbonization test facility. The test results showed the property of carbonized biomass fuel (higher heating value, etc.) had correlation with the yield*2 of carbonized biomass*3 (Fig. 1) (M14012). The yield of carbonized biomass, which is calculated from the feed rate of raw biomass and the production rate of carbonized biomass, was found to be an effective operational index of carbonization process. The test results also showed the hue angle*4 of carbonized biomass had correlation with the heating value of carbonized biomass (Fig. 2) [1]. Because the hue angle also had correlation with the fixed carbon and fuel ratio of carbonized biomass, the colorimetry was found to be a convenient method for estimation of carbonized biomass property.

2 Co-combustion characteristic of coal and carbonized biomass

Assuming the use of carbonized woody biomass at a high mixing ratio in a coal-fired power plant, co-combustion tests of coal and carbonized biomass where mixing ratios were set at 10% and 30% in calorific value were carried out by a single-burner combustion test facility. The temperature distribution in the furnace showed little difference between the coal mono-combustion and co-combustion of coal with the carbonized biomass (Fig. 3). However, the combustion rate*5 increased as the mixing ratio of carbonized biomass increased (Fig. 4).

3 Grindability evaluation of coal and carbonized biomass pellets

The reduction of transportation cost and storage space is expected by increasing the bulk density of carbonized biomass. Pelletizing of the carbonized biomass could increase the bulk density by up to four times. The grindability of a mixture of coal and carbonized biomass (mixing ratios were 5% and 10% in calorific value) was tested in a roller mill test facility. The grinding power of the mixture and the particle size of the product were equivalent to those of coal by pelletizing carbonized biomass.

*1 The ratio of fixed carbon to volatile matter.
*2 The ratio of production rate of carbonized biomass to feed rate of raw biomass in dry basis.
*3 Study commissioned by the Ministry of Economy, Trade and Industry.
*4 A measure of color phase which is a color component (color phase, saturation and brightness).
*5 The ratio of the burned combustible content to the combustible content in fed fuel.

[1] M. Taki et al., Proc. of the 10th Conference on Biomass Science, pp.11-12, 2014.

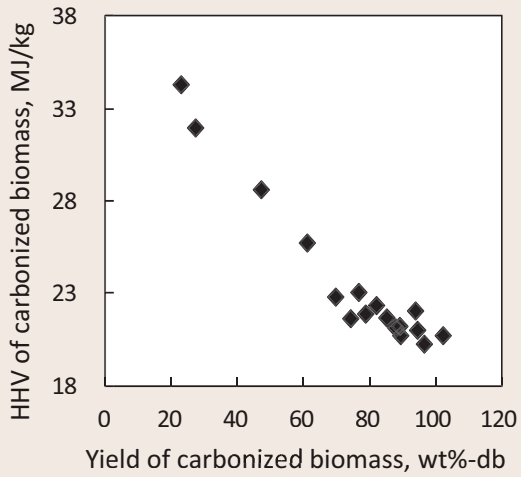


Fig. 1: Relationship between higher heating value (HHV) and yield of carbonized biomass

HHV of carbonized biomass showed a correlation with yield regardless of operation conditions in carbonization such as feed rate of raw biomass and carbonization temperature.

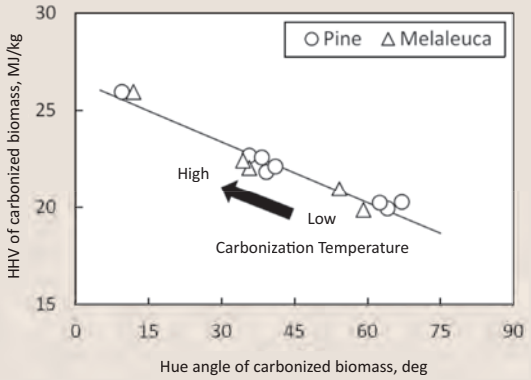


Fig. 2: Relationship between higher heating value and hue angle of carbonized biomass

The hue angle of carbonized biomass showed a correlation with HHV. HHV of carbonized biomass is easily estimated from the hue angle of pulverized carbonized biomass which is readily measurable by a color-difference meter.

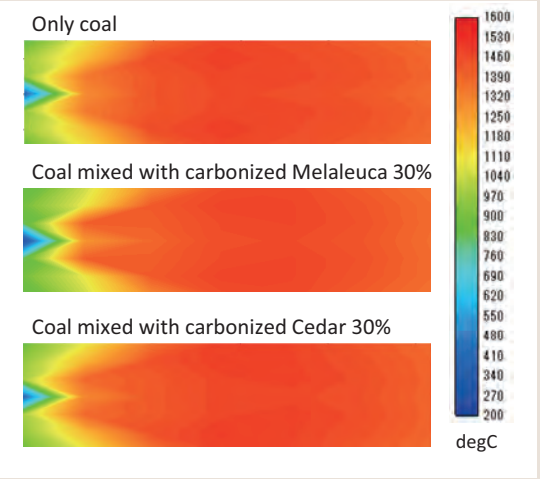
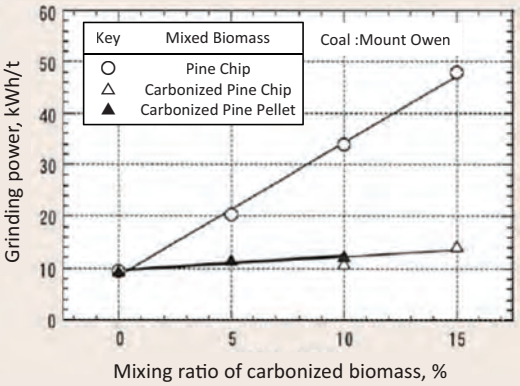


Fig. 3: Gas temperature distribution in co-combustion of coal and carbonized biomass

The figure shows gas temperature distribution in the combustion furnace in a cross-section containing the central axis of the burner. There was little impact from co-combustion of carbonized biomass.



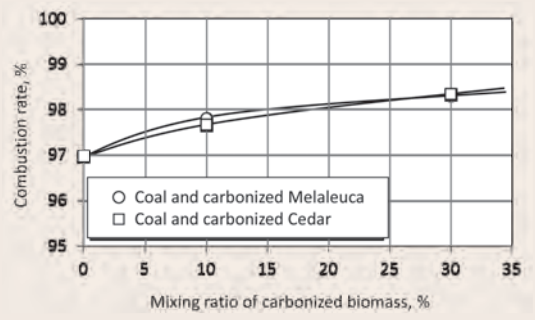


Fig. 4: Relationship between combustion rate and mixing ratio of carbonized biomass

Combustion rate was increased as mixing ratio of carbonized biomass increased, due to the ash content and fuel ratio of carbonized biomass being lower than that of coal.

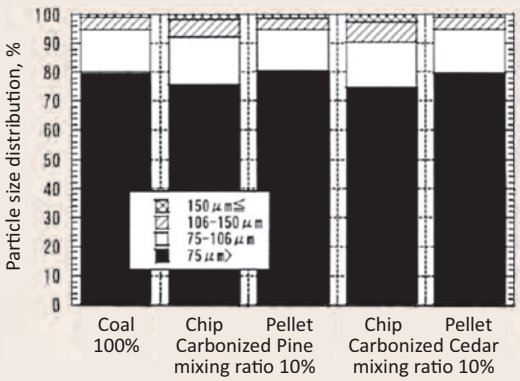


Fig. 5: Grindability of mixture of coal and carbonized biomass pellets

Grindability of carbonized biomass was equivalent to that of coal by pelletizing carbonized biomass.

Priority Subjects — **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, voltage stability, etc.) under the conditions created by the widespread use of renewable energy such as photovoltaics (PVs). In this study, we aimed to help stabilize power system operation by assessing its stability assuming the widespread use of PVs. First, we conducted tests using CRIEPI's Power System Simulator, which consists of small analog components that simulate generators, transmission lines and other power system components. We then used the results to develop and improve the models for CPAT*1 simulation analysis of the operation of power conditioning systems (PCS) and other components used with PVs.

Main results

1 Improving a PV model for Y-method simulation to support the analysis of angle stability after a system fault

To improve the accuracy of angle stability analysis performed assuming the massive interconnection of PCS for residential PVs, we improved the PV model for Y-method simulation, which can simulate phase-by-phase the responses of relays in PCS used with PVs, to better represent the characteristics of recovery after the stoppage of PCS, the re-operation of relays after identifying the undervoltage relay, and so on. Moreover, to improve the accuracy in simulating the transient response of the active current from PVs to a power swing caused by a system fault, we improved the model to change the operation of the PCS effective current limiter depending on whether or not the rated current is exceeded. These improvements enabled more accurate analysis of angle stability under various power system conditions such as PV operation status and interconnection points.

2 Assessment of the effects of the frequency feedback function of the PCS for PVs on angle stability

The PCS for residential PVs has an automatic islanding detection relay. The Standard of the Japan Electrical Manufacturer's Association mandates the use of a new islanding detection relay named AICOT (Anti-Islanding Control Technology) as a standard model of such a relay. Therefore, the number of PCS using this technology is expected to increase. With this technology, a feedback proportional to the frequency variation controls the output of the reactive power. In order to assess how the responses made by this feature may affect angle stability, we performed prototype testing using CRIEPI's Power System Simulator (Fig. 1), and the results showed the following. The phase of changes of reactive power from a PCS is determined by how the frequency variation is computed inside the PCS. When the period of the power swing caused by the system fault is longer, the phase of the reactive power fluctuation is more advanced in relation to the reversed phase of the detected frequency variation. The angle stability worsens when the phase advance is small, and vice versa (Fig. 2).

3 Assessment of the effects of various power system conditions on the angle stability of trunk transmission power systems

It is difficult to assess how the angle stability of trunk transmission power systems may be affected by a system fault under the conditions created by the widespread use of renewable energy because it may greatly differ depending on power system conditions such as the operation statuses of generators and renewable-based power supply systems, and also on whether or not any renewable-based power supply system is tripped after the fault, for example. Therefore, using the results of angle stability analyses performed on real power system data, we summarized how various power system conditions may affect the angle stability under the conditions created by the widespread use of renewable energy (Fig. 3). In a real power system, circuits in a voltage class of 66 kV or less are connected to many loads and renewable-based power supply systems. Therefore, models of lower-level power systems were added to those to be used for simple simulation of utility-level power system model*2 interconnected using 500 kV transmission lines and the effects of various power system conditions on the angle stability. Then we defined a scenario for the widespread use of renewable energy (Table 1) in order to perform an analysis using this power system model. We confirmed that this made it easy to identify the impacts on angle stability and their causes even when different power system conditions contribute in a complex manner (Fig. 4) (R14013).

*1 CPAT (CRIEPI's Power System Analysis Tools) was developed by CRIEPI. In this study, a transient stability analysis tool of CPAT was used. CPAT is used by all 10 electric utilities in Japan.
*2 IEEJ (The Institute of Electrical Engineers of Japan) WEST 10-machine system model.

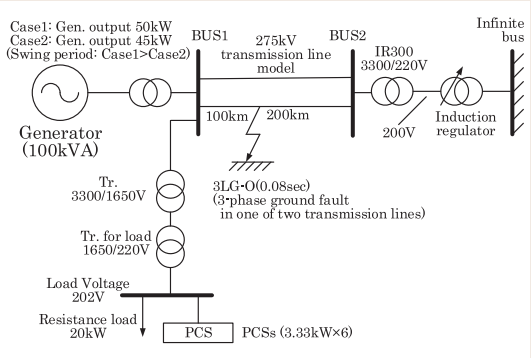


Fig. 1: A power system provided for experiment by CRIEPI's Power System Simulator

For each of two cases with differing swing periods, a generator output of 50 kW in one case and 45 kW in the other, the angle stability with the PCS frequency feedback function turned on was compared to that with the function turned off.

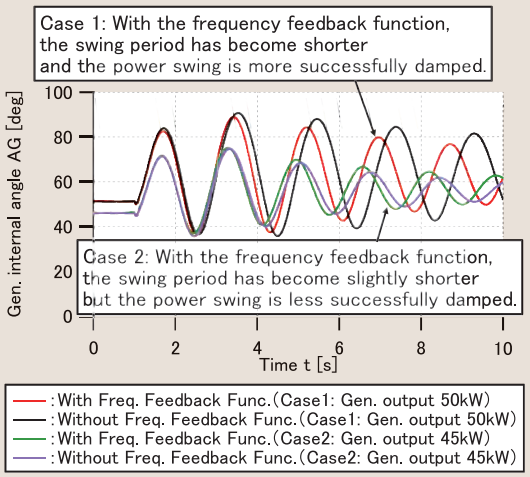


Fig. 2: Results of testing using CRIEPI's Power System Simulator

When the generator output is larger, the swing period caused by a system fault becomes longer and the phase of changes of the reactive power from the PCS for PV is more advanced. A larger phase advance resulted in higher angle stability.

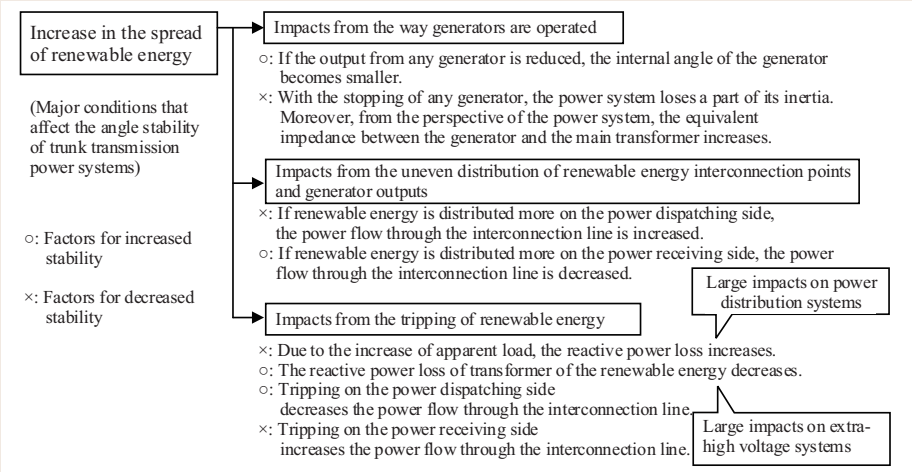


Fig. 3: Effects of various power system conditions on the angle stability of trunk transmission power systems

Table 1: Introduction scenario of renewable energy in a power system model

Base Condition	Off-peak condition of the IEEJ WEST 10-machine system model
Total capacity of generator and renewable energy(RE)	Pre-stage: Total gen. capacity 72GVA PV 0 GW, Wind turbine(WT) 0 GW
	Intermediate-stage: Total gen. capacity 70.83GVA[1] PV 11.25 GW, WT 2.81 GW
	Last-stage: Total gen. capacity 55.56GVA PV 21.30 GW, WT 5.33 GW
Generator minimum load	40% of generator rated capacity
Upper limit of the gen. capacity to shut it down	50% before renewable energy introduction[2]
Fault condition (System disturbance)	3-phase ground fault(70ms) in one of two transmission lines in the halfway point of the 'LINE 40' of the 10-machine system model
Tripping of PV and WT	・Nothing
	・Tripping 20% of the renewable energy in fault point neighborhood.

1) At the intermediate-stage, almost no generators are stopped.
2) When the total capacity of the interconnected RE exceeded the upper limit of the generator capacity to shut it down, the power flow through the interconnection line was increased to send the surplus power toward generator G10 in the WEST10 machine system.

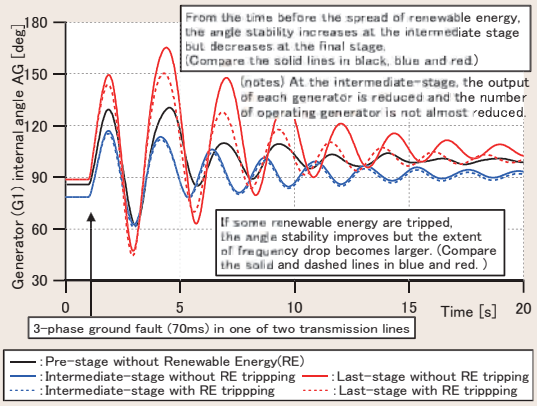


Fig. 4: Example of assessing impacts on angle stability under the conditions created by the widespread use of renewable energy

By evaluating the impacts shown in Figure 3, it is easier to identify how various power system conditions may affect angle stability as well as to determine the causes of such impacts.

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

Development of Precise Power Output Estimation and Prediction Techniques of Photovoltaic Power Generation

Background and Objective

Development of precise power output estimation and prediction techniques of photovoltaic power generation (PV) is necessary to suppress the impact of massive PV penetration on a utility power system such as a remarkable increase in reserve margin which is necessary for proper electric supply and demand operation. In order to contribute to cost reduction of utility system operations (such as the supply and demand operation), we are developing real-time estimation methods for the PV power output of not only local areas but also the entire area of the utility system, for the short-term ahead, less than several hours, prediction method of PV power output, long- term ahead prediction method of PV power output and a precise estimation and prediction system integrating the above methods.

Main results

1 Development of real-time solar irradiance prediction methods from geostationary satellite images for PV power output prediction

Reliable prediction of photovoltaic power yields is essential for balancing the supply and demand of electricity and a prediction interval of 1 minute is required for the network management. Geostationary satellite images are a promising data source for the photovoltaic power yield prediction. Although the interval of the data supply is 30 minutes at present, linear interpolation of the images is expected to permit us to predict large areal PV power output with a shorter interval owing to the smoothing effects of high frequency fluctuations of solar irradiance. Thus, spatially averaging 1 minute irradiances obtained by this interpolation were evaluated for one year (2011) in the Kanto district. Root mean square errors were 61.6 W/m^2 (12.9% of the average solar irradiance), which was comparable to those of 30 minutes average. As the forthcoming geostationary satellite has a high specification, the results have indicated the satellite is a promising candidate as a data source of PV power output prediction (Q14012).

2 Development of a method for estimating diffuse solar fraction toward precise PV power output predictions

For accurately estimating PV power output in electric demand and supply operation, a solar irradiance incident to a tilted PV array is to be used. In order to calculate the incident solar irradiance, the fraction of diffuse radiation to global radiation*1 is necessary. Therefore, using a radiative transfer model, we have developed a new method for estimating "cloud optical thickness" and also diffuse solar fraction from observed global solar irradiance. Comparing estimated diffuse solar fractions with observed ones, we obtained temporal variations similar to observations (Fig. 2), which suggests the potential for this method to be used in making precise PV output predictions (V14018).

3 Development of analyzing techniques for solar irradiance data observed at many sites to forecast fluctuation of PV power output

A statistical technique using solar irradiance observed at many sites is one of the promising methods for a short-term, thirty minutes to a few hours, forecast of PV power output fluctuation. However, due to the fact that one set of solar irradiance data is extremely large, data analysis techniques for preprocessing are indispensable to achieving a successful forecast. We have developed two methods; (1) Regression analysis by automatically selecting observation sites and weather data appropriate for the forecast according to their contribution to the forecast, and (2) Prediction of moving time of a large cloud by evaluating relevance among wave-forms of solar irradiance at different observation sites (Fig. 3). We have confirmed that the method (1) can select observation sites and weather data which are effective to the precise forecast. Furthermore, we will use the moving time of a large cloud guessed by the method (2) to improve the forecast (R14019) (R14014).

*1 Sum of the direct solar radiation, which reaches the ground surface directly from the sun, and the diffuse solar radiation, which has been scattered once or more by clouds and/or aerosols.

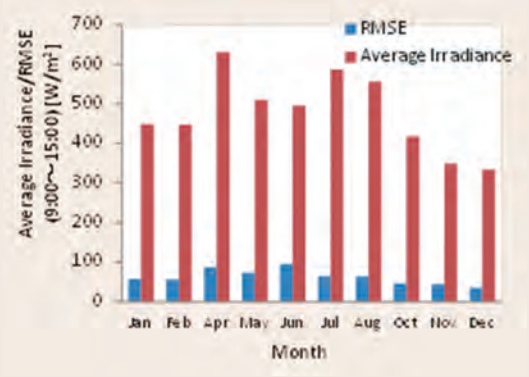


Fig. 1: Monthly errors of solar irradiance predictions from geostationary satellite images

This figure shows root mean square errors (RMSEs) of 1 minute irradiance prediction between 9:00-15:00. As March and September were used for training data of statistical parameters, we did not carry out the evaluation of these months. The resulting annual RMSE was 61.6 W/m² (12.9% of the average solar irradiance).

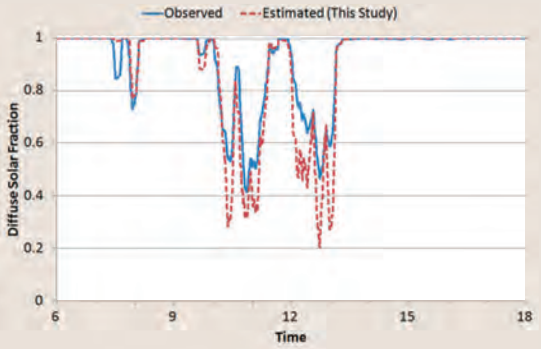


Fig. 2: An example of validating the new method for estimating diffuse solar fraction (in CRIEPI Abiko, Nov. 6, 2014)

Although some empirical methods for estimating diffuse solar fraction already exist, the new proposed method based on a solar radiative transfer model enables more accurate estimations in various atmospheric conditions. Estimated values tend to be somewhat smaller than observed ones when clouds are optically thin, but estimated temporal variation of diffuse solar fraction agrees reasonably well with the observation.

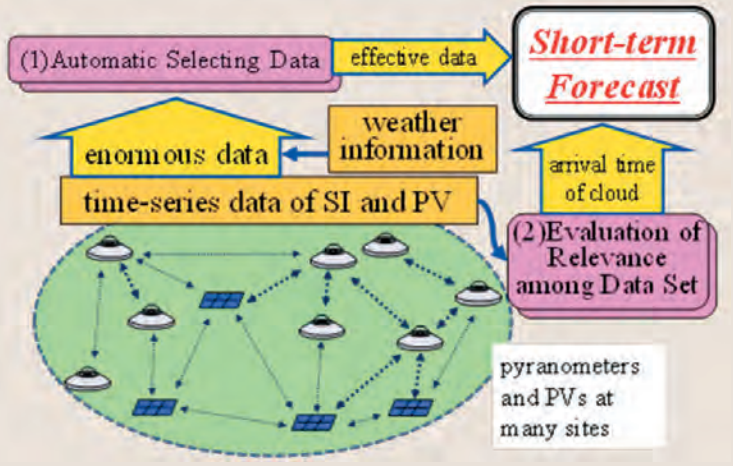


Fig. 3: Outline of Analysis Techniques for Solar Irradiance and PV Data

(1) We have developed a technique to select effective observation sites for forecast of short-term fluctuation of PV power output, as some sites supply noise data to increase the forecast error. The selection is based on the degree of contribution to the forecast. The technique has selected 15 sites from approx. 60 sites. As a result, the forecast accuracy has been better than that using all sites.

(2) We have developed a technique to realize a time-lag of PV power output fluctuation patterns between different sites based on evaluation of the degree of relevance among the patterns, as the time-lag can be regarded as arrival time of a large cloud from one site to another. The technique has demonstrated an appropriate time-lag of PV power output fluctuation pattern measured at 30 sites.

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

Development of ICT Infrastructure Building Techniques Based on General-purpose Communication Technology

Background and Objective

Currently, for power system protection, the proprietary and legacy communication method is still widely used rather than general-purpose communication technologies such as Internet Protocol (IP). Customer communication networks including smart metering and communication networks for monitoring and maintenance of power system facilities are yet to be developed and general-purpose communication technologies are also expected to be applied to the communication. This project investigates the improvement and validation of the developed techniques based on general-purpose communication technologies which contribute to reducing construction cost of utility communication networks.

Main results

1 Applicability evaluation of IP-based microwave radio communications for power transmission line protection

To apply IP-based communications to trunk power transmission line protection with their reliability and cost effectiveness maintained, the IP-based microwave radio system has yet to be utilized. Since power transmission line protection requires stringent communication delays, communication performance of the IP-based microwave radio system was evaluated with respect to end-to-end delays and delay variations (Fig. 1). The evaluation showed that a time synchronization scheme implemented in microwave radio equipment could realize IP-based power transmission line protection. It also clarified that the number of communication channels and their end-to-end distances were determined by the interface speed and the number of microwave radio equipment installed (Table 1) (R14007).

2 Development of an estimation method for impedance on electrical wiring in dwellings for PLC system design

A high-speed kHz-band PLC (Power Line Communication) is an effective communication technology for smart-meter networks. It is necessary to estimate the typical impedance value (Zh) of electrical wiring in dwellings for easy evaluation of applicability to apartment buildings. It was clarified that the impedance of appliances is extremely low and Zh is governed by reactance of wiring cables by measuring impedance characteristics in actual dwellings. Based on the above results, we presented a simple equation to estimate Zh from the average length of wiring cables and number of parallel circuits (Fig. 2). By using the equation, it becomes possible to evaluate applicability of PLC to apartment buildings without measuring the appliance characteristics (R14004).

3 Outdoor field testing of a multi-point sensing system based on a remote optical power supply

We have developed a new multi-point optical sensing system (MPOSS) based on remote optical power supply technology. Prototype optical nodes for outdoor installation were developed, and are installed along the distribution line at the Akagi Testing Center (Fig. 3). Continuous operation testing in an outdoor field was conducted from November 2014 to March 2015, and it was confirmed the optical nodes and data acquisition function have stably operated by remote optical power supply. The results shows the MPOSS can be applied to transmission line monitoring in winter.

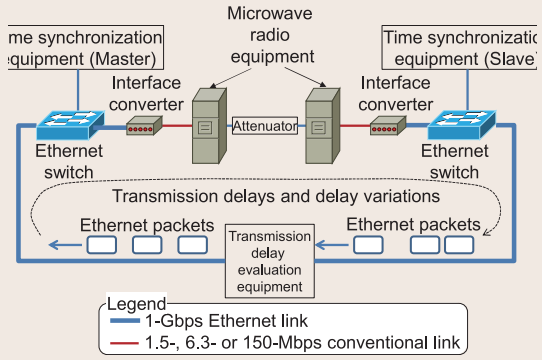


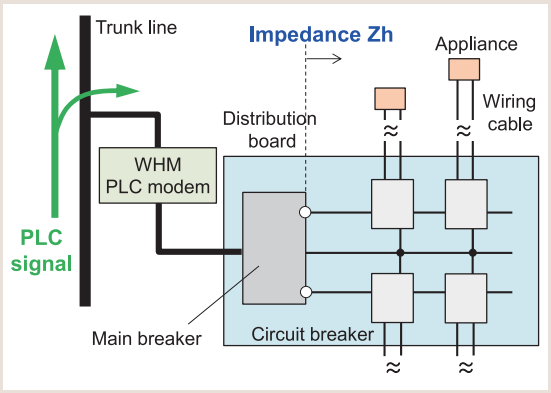
Fig. 1: System configuration for evaluating transmission delay performance

Transmission delay performance of a microwave radio link connected to Ethernet switches (IP equipment) and master/slave time synchronization equipment was measured.

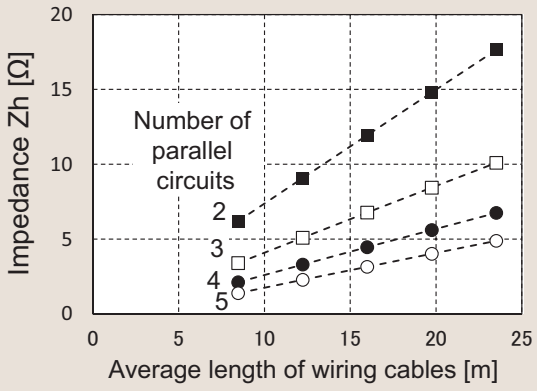
Table 1: Relationship between interface speeds of microwave radio equipment and viable protection relay communication channels accommodated

Radio equipment interface speed [Mbps]	With or without branching	Number of repeater equipment	End-to-end communication distance [km]	Number of communication channels
1.5	Without	1	100	2
6.3	Without	4	250	3
	With	1	100	3
150	Without	4	250	5

Viable communication channels accommodated and end-to-end distances are determined by the existence of branching and the number of repeaters. The end-to-end communication distances are reduced by the queuing due to incoming frames from intermediate branch circuits.



(a) Configuration of wiring and definition of Zh



(b) Estimated results of Zh

Fig. 2: Estimation method of impedance on electrical wiring (Zh) in dwellings

Impedance of dwelling side including all wiring cables and appliances is defined as Zh. It depends on average length of wiring cables and number of parallel circuits. So, Zh can be estimated from these parameters.

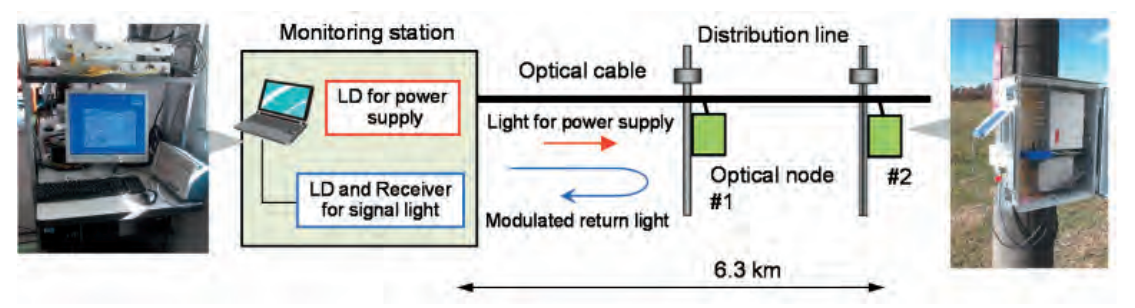


Fig. 3: Field testing setup of multi-point sensing system based on optical power supply

Two optical nodes, at a distance of 6 km from the monitoring station, are driven by light for power supply. Sensing information collected to the optical node is transmitted by a signal light with a wavelength differing to that of light used for power supply.

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

Development of Technologies for Next-generation Power Distribution Networks

Background and Objective

Photovoltaic generation (PV) for both residential and non-residential was introduced based on a feed-in tariff system in an accelerating way. As a result, power transmission lines and power distribution lines became overloaded, and reverse power flow to a power distribution line occurs in some areas. Consequently, it is becoming difficult to secure stable power supply.

In this report, problems relating to operation and control in power distribution systems when renewable energy is introduced in large quantities are identified, and methods of operation and load management under normal and abnormal situations are developed using information from section sensors. This has contributed to maintaining the stability of power distribution systems.

Main results

1 Estimation by comparing voltage regulation method of transformers for distribution in substation systems with PV large penetration

The voltage control methods of transformers in distribution substations that are adopted as equipment of the current state are program control, scalar type load drop compensation and vector type load drop compensation. We must evaluate the effect of system voltage regulation regarding these voltage control methods and clarify the optimal method (Fig. 1(a)).

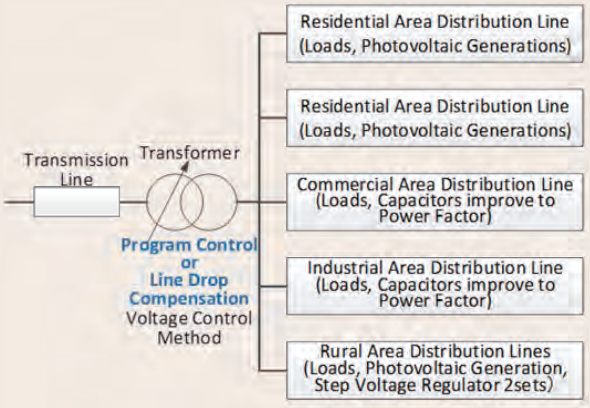
As a result of comparing these voltage control method, we cleared that vector type load drop compensation is suitable method, and adding control of maintaining power factor of photovoltaic generations was brought to more suitable method. Moreover, we cleared that when considering this, it's necessary to consider impedance of transmission power line (R14021).

2 Improving voltage imbalance of power distribution systems by using voltage data from section switches

In middle voltage distribution lines with three phases, voltage becomes imbalanced if single phase transformers are connected to the distribution line in imbalance. It is possible that increasing PV causes voltage imbalance. In order to solve these problems, we investigated the relationship between imbalance of the connection load and imbalance of the voltage. From the investigation results, we proposed a connection method of a pole-mounted transformer to improve the voltage imbalance of the power distribution system by using voltage data from the three phase measurement function of the switch. We confirmed that the method is effective for improving imbalance of the voltage by comparing the method with the conventional method (Fig. 2) (R14003).

3 Development of an estimation method for photovoltaic generation output using power flow information from section sensors in distribution systems

We proposed a new separation method of the power generation curve of PV systems and demand curve as a solution of the overcurrent problem and other power quality problems. Power flow measured by using section switch with sensor is resolved into PV output and load every measurement interval, and PV output is resolved into active power and reactive power by the method. PV output can be calculated by integrating the active power. Average specific inaccuracy of data for 10 days was found to be 7% through a comparison with PV output data measured via a sensor (Fig. 3) (R14012). We confirmed that the method is effective for faults in distribution lines as well as planning distribution equipment because the method can estimate in real time.



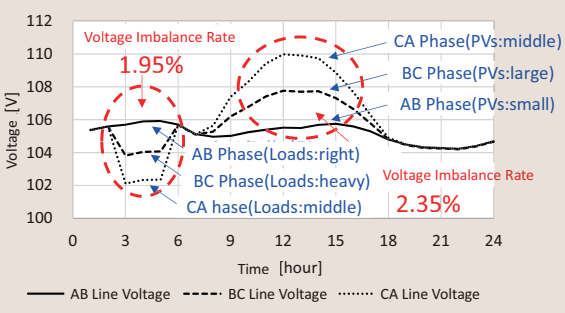
(a)Bank model for estimation

Bank Control Method	Introduction Limit Rate of PV
Program Control (Schdule Operation)	less than 20%
Scalar Type Line Drop Compensation	less than 20%
Vector Type Line Drop Compensation	40%
Vector Type Line Drop Compensation and Power Factor Constant Control of PV	60%

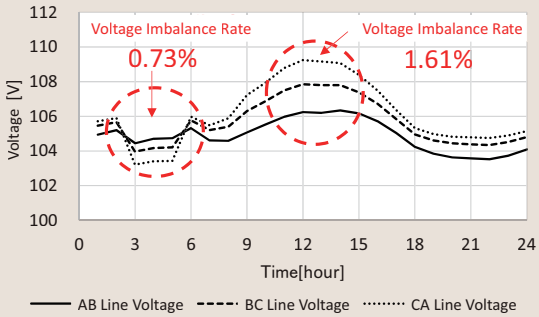
(b)Calculation results

Fig. 1: Comparing results of voltage control method for transformers of substations in distribution systems

As shown in Fig. 1, in severe bank model of substation transformer relatively, the method of voltage control is compared and estimated by increasing the PV introduction rate in the view point of rate at starting voltage deviation (Fig. 1 (b)).



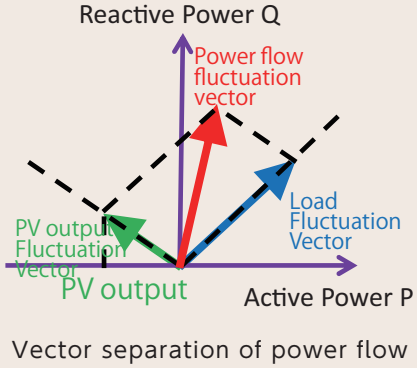
(a)Before adopting improving method



(b) After adopting improving method

Fig. 2: Calculation example when middle voltage is adopted improving method

These results are calculated based on a standard residential distribution model, and shows that voltage imbalance reduces throughout the day.



Vector separation of power flow

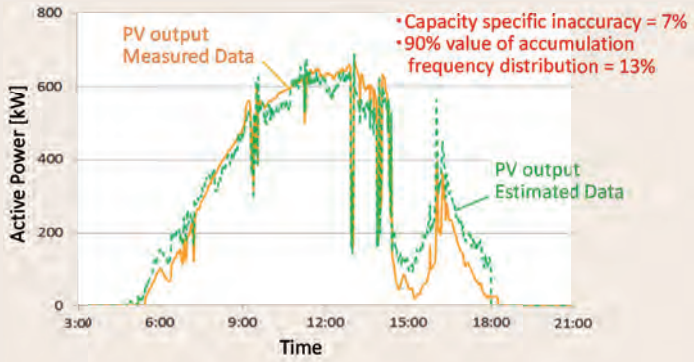


Fig. 3: Outline of estimation method of photovoltaic generation output and estimation results

As shown in the left side of Fig. 3, the power flow vector measured by using section switch with a sensor can be resolved into PV output vector and load vector, and PV output can be resolved into active power and reactive power. As a result, PV output can be estimated as shown in the right side of Fig. 3.

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

Assessment of the Value of Next-generation Demand Management

Background and Objective

In the wake of the Great East Japan Earthquake, electricity saving has become more entrenched and various attempts to utilize Demand Response (DR), such as encouraging peak shaving or load shift of electricity demand through the electricity rate, have attracted public attention for considering electricity demand. Moreover, DR is expected to be utilized for the stabilization of electricity supply systems including the response for rapid installation of photovoltaic (PV) systems or regulatory reform of the electricity market.
In this project, we analyze behavior on energy saving and assess the feasibility of electricity demand management by DR, from both the viewpoints of the electric utility and customers, in order to choose the desirable method of demand management for the future and for identifying any issues which must be solved or necessary schemes.

Main results

1 Ex-post analysis of electricity saving measures in the residential and commercial sector during 2011-14

Based on a questionnaire survey on energy saving conducted between 2011-2014, we found awareness of electricity saving and the level of saving behavior had been declining even though the saving level had been maintained in the summer season for both office buildings and households (Fig. 1 and 2). The factor for energy saving has also been changing so that the effects of switching to energy-efficient appliances and increased electricity prices covered the decline in awareness of electricity saving and the level of saving behavior. This result is important for electric utilities to estimate electricity demand (Y14013) (Y14014).

2 Technology trend of demand analysis and exploratory verification for the utilization of smart meter data

Considering the increased introduction of smart meters, we completed a regression analysis to disaggregate the converted data of actual records for four households in units of 100 Wh and one hour interval into i) temperature-sensitive demand, ii) variable demand, and iii) static demand, and confirmed the temperature-sensitive demand was in relatively good agreement with air conditioner demand (Fig. 3). This method is anticipated to be used to propose advice on energy saving or new services which are useful for life (Y14003).

3 Cost-benefit analysis of voltage stabilizing measure in distribution network with large-scale introduction of PV systems

Reactive power compensation is a measure against the voltage-rise in distribution networks caused by reverse power flow from roof-mounted PV systems. The idea of installing a reactive power compensator in low-voltage distribution networks has been previously proposed, because it is close to the PV location. This research proposed four installation schemes (Table 1) and a cost comparison method of the low-voltage reactive power compensator. In this method, the most cost-effective installation scheme can be selected, calculating the equipment capacity needed for voltage stabilization. As shown in Fig. 4, pole-mounted case and consumer-end case have the least equipment capacity due to optimum location minimizing total capacity. In these cases, reactive power compensators are installed where voltage-rise problems occur; hence, the cost-effectiveness is high at low PV penetration when voltage-rise problems occur locally (Y14010).

4 Current utilization status of demand-side resources for ancillary services in the U.S.

We researched the trends of utilizing demand-side resources for ancillary service in the U.S. to find out if demand resources have the ability to provide ancillary services through literature researches of 6 ISO/RTOs (Table 2). Electric Reliability Council of Texas is worthy of attention as a reference case of future Japanese frequency regulation due to its power system scale and installation scale of renewable energy resources. Another notable ISO will be the California ISO where a significant amount of photovoltaic has been installed. We extracted key points when ancillary services provision from demand-side resources are applied in Japan; i) stepwise introduction of demand responses into the ancillary service market, and ii) enhancement of the reliability evaluation method of demand-side resources (Y14011).

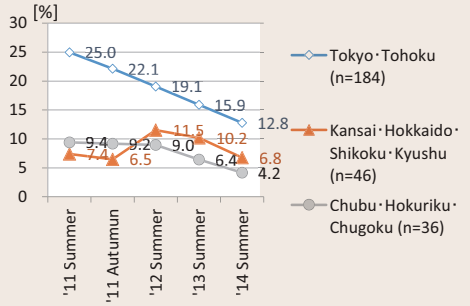


Fig. 1: Rate of overall reduction in office buildings in summer

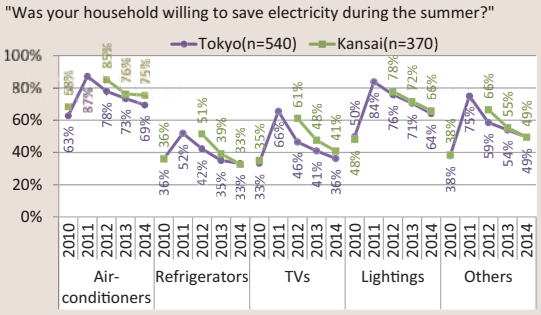


Fig. 2: Awareness of electricity saving in households

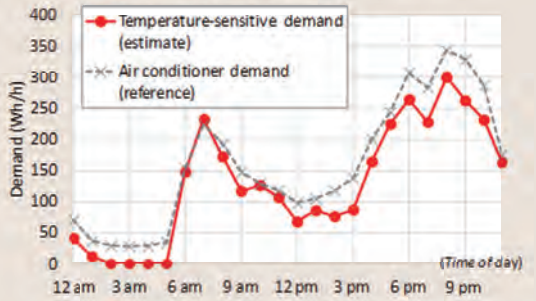


Fig. 3: Yearly averaged temperature-sensitive demand and air conditioner demand

Table 1: Case settings for installation of reactive power compensator

Case	Type of reactive power compensator	Installation location
High-voltage line	Static Var Compensator (SVC)	● Terminal node of high-voltage line ● Discrete capacity with 300kVA
PV-node installation	Use inverter owned by consumers or install equipment for reactive power compensation	● Consumer end where PV is installed
Consumer-end installation		● Optimal location among all consumer end to minimize total capacity
Pole-mounted	Pole-mounted equipment	● Optimal location among all power pole to minimize total capacity

Pole-mounted case and consumer-end case have the least equipment capacity, followed by PV-node installation case, and then high-voltage line case. The suppressive effect on voltage-rise by compensating reactive power depends on the reactance value. Because service wire has a small reactance value, the pole-mounted case, in which equipment is installed before the service wire, and consumer-end case, in which equipment is installed after the service wire, have almost the same capacity.

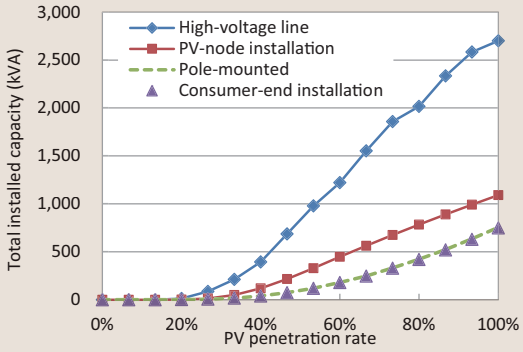


Fig. 4: Total installed capacity of reactive power compensator: average value of randomly-generated 1,000 scenario

Table 2: Current status of utilizing demand-side resources for ancillary services in each ISO/RTO

ISO/RTO		ERCOT	PJM	NYISO	ISO-NE	MISO	CAISO
Peak demand [MW] (year)		68,305 (2013)	163,848 (2011)	33,956 (2013)	27,379 (2013)	130,000 (2013)	46,847 (2013)
Capacity ratio of wind power and photovoltaic to peak demand (year)		16.1% (2013)	6.5% (2012, 2013[1])	4.3% (2013)	4.7% (2013)	9.2% (2013)	22.3% (2013)
Participation of demand side resources on ancillary service market		Yes	Yes	Yes	Yes	Yes	No
Participation capacity of demand side resource	Frequency regulation	37 MW (2014)	2.46 MW (2013)	100MW[3] (2012)	—	—	—
	Spinning reserve	3,300 MW (2014)	605,521MWh[2] (2013)		—	—	—

ERCOT: Electric Reliability Council of Texas, NYISO: New York ISO, ISO-NE: ISO New England, MISO: Mid-Continent ISO, CAISO: California ISO

*1 Some states aggregated data in 2012 and others in 2013

*2 This unit represents the product of contract capacity [MW] and contract period [hour].

*3 Summation of capacities of regulation and reserve

In the spinning reserve market of ERCOT, where a significant amount of wind power generation has been installed, demand resources account for 50% of the required amount of spinning reserve most of the time, contributing substantially. On the other hand, utilizing demand-side resources for frequency regulation is still in the testing stage.

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, to use low-GWP (global warming potential) refrigerants, and to 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 process heating and so on. We wish to contribute to the launching and popularization of heat pumps attractive to end users.

Main results

1 Efficiency evaluation for residential heat pump water heaters

With our test facility for the development and evaluation of residential heat pumps, we have evaluated the energy consumption efficiency of a residential heat pump water heater with CO_2 refrigerant, Eco-Cute, under various operating conditions with the parameters of hot water demand, heat source air temperature/humidity and so on. We will make efficient use of these results to set performance evaluation standards of heat pump water heaters.

2 Elucidation of commercial heating tower's frosting/defrosting characteristics

With our new test facility for the development and evaluation of industrial and commercial heat pumps, we have elucidated the frosting/defrosting*1 characteristics of a commercial heating tower*2 (Fig. 1) under various operating conditions with the parameters of heat source air temperature/humidity and so on, through some defrosting methods. Moreover, we have devised a new defrosting method with a shorter period and reduced energy consumption for defrosting. We will make efficient use of these results to improve performance and to expand the applicable regions of heating towers.

3 Efficiency evaluation for industrial heat pump steam generators

With our new test facility, we have evaluated steam discharge rate and system COP*3 of an industrial heat pump steam generator, SGH165*4 (Fig. 2), under various operating conditions with the parameters of inlet temperature of heat source water, steam discharge pressure and so on (Fig. 3). Moreover, we have elucidated technical problems for the expansion of heat pump steam generators through inquiries to end-users, plant engineering companies, manufactures and so on. We will make efficient use of these results to improve the performance of heat pump steam generators and to develop new related technologies.

*1: Frosting is the freezing of water contained in cold outside air on the surface of a heat exchanger. As frost become a thermal resistance and an obstruction of air flow in a heat exchanger, defrosting, in other words, the melting of frost, is essential to the operation of a heating tower and air source heat pump.

*2: A heating tower is a heat exchanging system in which brine, referring to antifreeze solution, absorbs heat from cold outside air. A water source heat pump chiller can generate hot water for room heating through using air source heat in combination with a heating tower. Moreover, it plays the role of a cooling tower when a water source heat pump chiller generates cold water for room cooling. There is one in operation at the Tokyo Sky Tree and so on.

*3: The system COP is a kind of energy consumption efficiency defined as heat output of generated steam divided by electric power input, exceeding 1 by using waste heat of hot drainage.

*4: SGH is an abbreviation of Steam Grow Heat pump and applicable to industrial heating processes, for example, sterilization, concentration, drying, distillation and so on. There are two SGHs; SGH120, which generates 120℃ steam, and SGH165, which generates 165℃ steam, through the recovery of waste heat from drainage in factories. These are in operation at some factories which manufacture bioethanol, medicine and so on.

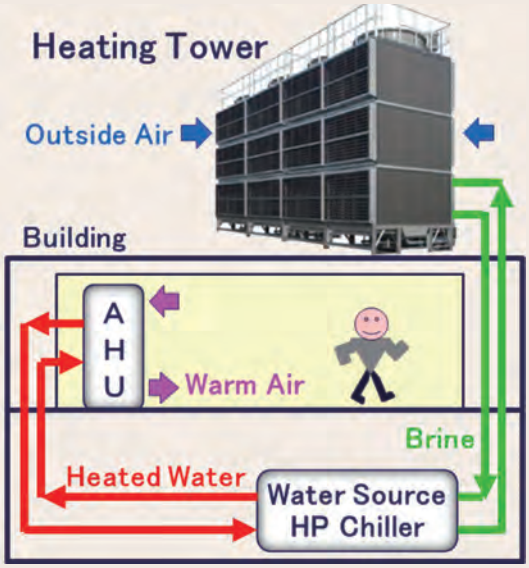


Fig. 1: Commercial heating tower

In a heating tower, brine, referring to antifreeze solution, absorbs heat from cold outside air. A water source heat pump chiller absorbs heat from brine and generates heated water. In an air handling unit, heated water releases heat to indoor air to warm a room.

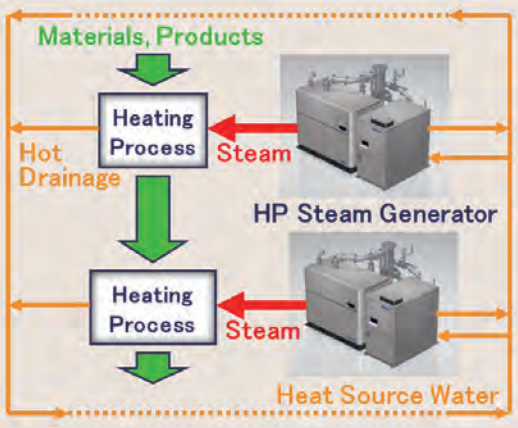


Fig. 2: Industrial heat pump steam generator

Steam condenses and converts to drainage after being used in various heating processes in factories. Efficient use of energy is possible by recovering waste heat of drainage. The higher the temperature of drainage, the higher the efficiency of the heat pump steam generator.

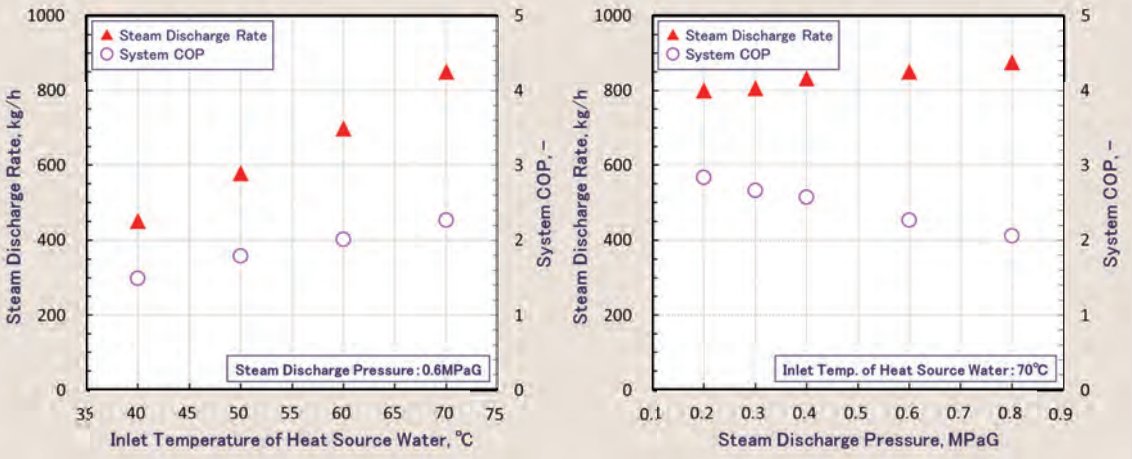


Fig. 3: Performance test results of the heat pump steam generator SGH165

The figure to the left indicates the impact of inlet temperature of heat source water on steam discharge rate (▲) and system COP (◯), while the figure to the right the impact of steam discharge pressure on the same two points. The condition for basic performance of the SGH165 is that the steam discharge pressure is 0.6MPaG (saturated steam temperature 165℃) and inlet temperature of heat source water is 70℃.

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

Secondary batteries are expected to be utilized not only for load leveling energy storage, but also for stabilization of electric power grid systems connected with renewable power sources such as photovoltaic and wind power generators. It is thus important to establish technologies which contribute to exact evaluation of secondary battery remaining life time and to keep improving "safety" technologies for their long-period operations. We will elucidate the degradation mechanism of lithium-ion batteries (LIB), which is excellent in its energy density and energy efficiency, as an accurate understanding of the degradation mechanism makes precise life-time evaluation possible. We will also establish comprehensive analysis methods of LIB for extending life and improving safety.

Main results

1 Evaluation of cell capacity changes during charge-discharge cycle tests

Charge-discharge cycle tests of cells with lithium titanate (LTO) anode* selected as a practical stationary use lithium-ion battery (LIB) were examined at a constant electric current (Fig. 1). Charge-discharge cycle tests were examined at 45°C to accelerate the degradation of the cells, and the discharge capacities were periodically checked at 25°C for evaluation of cell life (Q14009). As a result of the charge-discharge tests for a maximum of 5,000 cycles over approx. 1 year, the cells were found to have capacities of more than 98.9% of the initial capacities, even in the case of the most degraded cell. Therefore, the cells used in this study were expected to have long life (Fig. 2, open symbols).

2 Quantitative evaluation method of cell capacity changes

The degradation of the cell includes various factors, therefore, in order to clarify the degradation characters of the cell, it is important to divide the capacity change into each factor and understand their characters. It is considered that the cell capacity fading can be divided into fading during storage without electric current (storage fading factor, ΔQ_t) and fading by repeating charge-discharge reactions (cycle fading factor, ΔQ_e).

The capacity change of charge-discharge cycle tests includes both of the above fading factors, therefore, in order to distinguish the cycle fading factor, an evaluation method of the capacity based only on charge-discharge reactions (Q_e) was suggested by obtaining the storage fading factor from the results of the storage tests without electrical current (Fig. 2). This method enabled quantification of the cycle fading factor as the difference between the initial capacity and degraded only charge-discharge reactions.

Furthermore, it was elucidated that the cycle fading factor could be divided into the fading with (ΔQ_{eR}) and without (ΔQ_{eC}) the influence of internal resistance of the cell by examining the capacity checks at multiple currents (Fig. 3(a)). Capacity fading by internal resistance (ΔQ_{eR}) was found to increase with the square root of operation time, which may be due to the growth of a coating layer at the electrode surface as was generally considered (Fig. 3(b)).

From the proposed evaluating method in this study, the capacity fading of the cell was able to be quantitatively divided into three parts, the storage fading factor and the cycle fading factor with and without the influence of internal resistance (Fig. 4). The quantitative evaluation of cell degradation will be utilized for the planning of long-term operation through the clarification of the degradation mechanisms of each factor.

* SCiB™ Manufactured by Toshiba, rating capacity: 20 Ah.

Fig. 1: Lithium-ion cell and charge-discharge test equipment used in this study

The single cell (pictured lower right: provided by Toshiba) was set into the thermostatic chamber (pictured upper right), and the charge-discharge test was examined with a power device (pictured left).

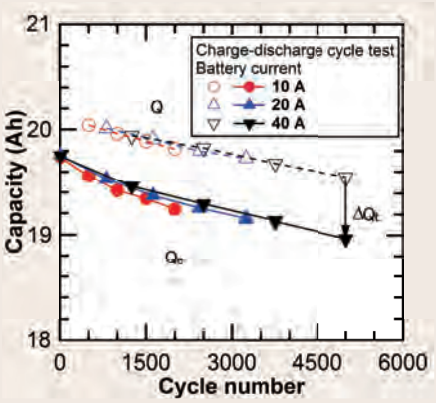


Fig. 2: The dependence of the discharge capacity after the cycle test (Q) and the degraded capacity (Q_e) extracting storage fading factor (ΔQ_t) with cycle numbers

The capacity degraded only the charge-discharge reactions (Q_e) was obtained by extracting the storage fading factor (ΔQ_t) from the discharge capacity after the cycle test (Q). ΔQ_t was the difference between the initial capacity and the capacity after the storage test. Each plot was the averaged value of three samples.

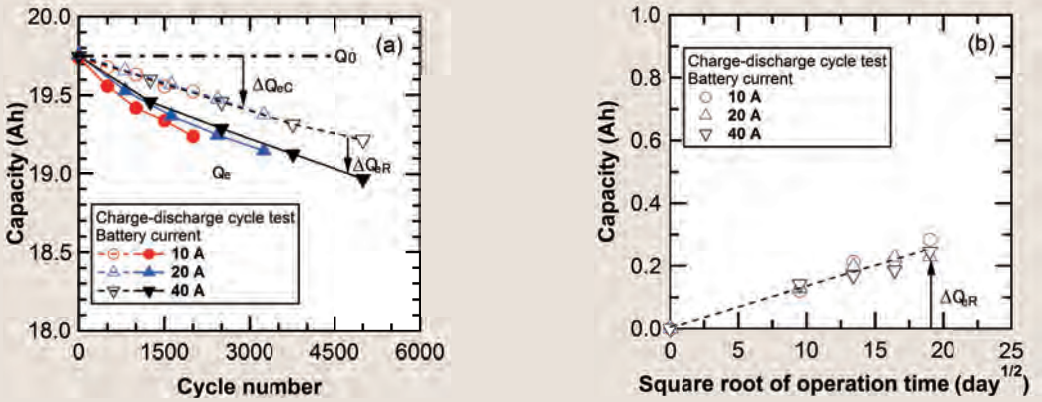


Fig. 3: The dependence of the capacity fading other than the internal resistance of the cell (ΔQ_{eC}) and that due to the internal resistance of the cell (ΔQ_{eR}) with cycle numbers and operation time during the charge-discharge cycle tests

The discharge capacities at currents of 10 A and 20 A in the capacity checks were plotted, and a line was drawn between them and extrapolated to the current of 0 A. This capacity was defined as the virtual 0 C rate capacity. The difference of the virtual 0 C rate capacity between the initial value and the capacity after the test was defined as ΔQ_{eC}. ΔQ_{eR} was defined as the remainder obtained by subtracting ΔQ_{eC} from the cycle fading factor (ΔQ_e: ($Q_0 - Q_e$)). Each plot was the averaged value of three samples.

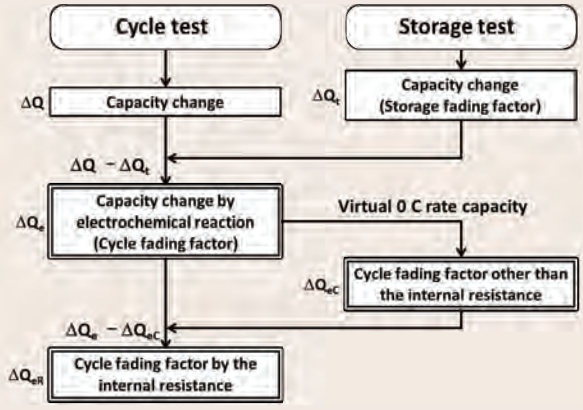


Fig. 4: Flow chart of the quantitative evaluating method for the discharge capacity change in this study

The cycle fading factor (ΔQ_e) was obtained by subtracting the storage fading factor (ΔQ_t) from the discharge capacity during the charge-discharge cycle test (Q). Furthermore, the cycle fading factor was divided into the capacity fading by the internal resistance (ΔQ_{eR}) and that other than the internal resistance (ΔQ_{eC}).

Basic Technology Subjects

Socio-economic Research Center

Brief Overview

Integrating academic expertise in economics, risk management, legal studies, energy system analyses, and environmental sciences, the Socio-economic Research Center develops viable options for the sound management of electric utilities as well as energy and environmental policies and thereby addresses the challenges of the industry.

Achievements by Research Theme

Utility Management and Policy

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

- After the monopolistic supply area is abolished through liberalization, the relationship will also change between incumbent power companies and local communities in the previous supply area. This study clarifies the factors which make the "community-based strategy" effectively function in the new business environment. The case study of SSE in the UK shows that the community-based strategy is a feasible option for a private company even in the competitive and demand-shrinking market. However, in the long-term, SSE envisages the strategy to be sustainable by continually providing innovative values to customers (Y14008).
- It was found that some European energy suppliers provided a variety of tariffs after full liberalization of the retail electricity market in the UK and Germany (Table 1). Some customers switched their electricity tariffs while they didn't switch electricity suppliers. It was also found that some energy suppliers (such as Centrica in the UK) provided energy related services in addition to retail sales of electricity and gas, and acquired a significant number of customers for such services. Energy suppliers who provide a variety of services strive to develop face-to-face marketing channels and skilled human capital to provide such services (Y14023).

Economic and Social Systems

The team focuses on providing useful information on electricity demand forecasts and clarifying socio-economic risk factors for the electric power industry, by analyzing the impacts of population aging in Japan and economic trends in the world on Japan's economy and energy markets.

- Forecasted results of the number of regional households by household types show that the share of the elderly single-person households over 65 will increase from 8-12% (2010) to 13-18% (2030). It was also demonstrated that, assuming constant electricity saving rates and electrification rates in the future, the change in household-types including an increase of single-person during 2010-2030 will decrease the average residential electricity demand per household by 0.04% per year in Japan, decreasing it in most regions (e.g. -0.10% in Shikoku), while increasing the average demand by 0.04% in the Tokyo Metropolitan Area (TMA) (Fig. 1) (Y14009).
- We attempt to make use of the data from "Energy Consumption Statistics by Prefecture" for economic analysis on electricity demand in industrial and commercial sectors. It was observed that electricity demand in the industrial sector declined in the Tokyo and Kansai regions. In contrast, the commercial sector is displaying nationwide growth. We also estimated electricity demand functions and found that falling electricity rates in the period of 1990-2010 have a relatively low impact on electricity demand growth in both the commercial and industrial sectors (Y14015).

Energy Technology Assessment

While rebuilding a new set of methodology of energy technology assessment, the team strives to tackle newly emerged institutional and technological challenges caused by the large-scale introduction of renewable sources of energy as well as the prolonged cease of nuclear power unit operation, and thereby support reliable energy and electricity supply in a sustainable manner.

- We developed a method to analyze the power mix with thorough consideration of balancing necessities for load frequency as well as kWh under a large-scale introduction of intermittent renewable. The method proved effective in the grasping of operational needs for conventional power units and curtailment of renewable generation, as well as their associated costs (Y14002).

As a result of life-cycle analysis of CO2 emission of wind farms, since the 'floating offshore' wind farm employs a large floating body which weighs 10 times larger than the wind turbine itself, the life-cycle CO_2 emissions per kWh generated (LC-CO_2 emissions) of the former were found to be 4 times greater than onshore and implanted offshore wind farms. These results concluded the LC-CO_2 emission assessment on the 2009 standard for all commercial generation technologies currently available (Y14018).

Table 1: Electricity tariffs and services of major energy companies in the UK and Germany

		UK				Germany	
		Centrica/British Gas	SSE	E.ON UK	EDF Energy	RWE	E.ON
Electricity tariff	Variable rate	○	○	○	○	○	○
	Fixed rate	○	○	○	○	○	○
	Dual fuel (electricity and gas)	○	○	○	○	×	×
	Green electricity tariff	×	×	×	×	△ (abeyance of application, Feb. 2015)	○
	Online account	○	○	○	○	○	○
Services (paid)	Water heating and room heating system	・Sales and installation ・Maintenance	・Sales and installation ・Maintenance	×	・Maintenance	×	×
	HEMS	・Controller of room heating	・Controller of roome heating	×	・Controller of roome heating	・HEMS (e.g. controller of air-conditioner and lighting)	×
	Other	・Maintenance of electric and gas appliances ・Maintenance of drain ・Charging system for EV etc.	・Care of electric wiring ・Telecommunication services	×	×	・Energy consulting ・Sales of energy efficient products ・Charging system for EV, Home solar generation system, Battery	・Charging system for EV, Home solar generation system

(Note) ○: provided, ×: not provided, △: provided but can't be applied during this investigation
(Reference) Summarized by CRIEPI based on information available atenergy companies websites

Some European energy suppliers provided a variety of tariffs and energy related services after full liberalization of the retail electricity market in the UK and Germany and, as a result, acquired a significant number of customers.

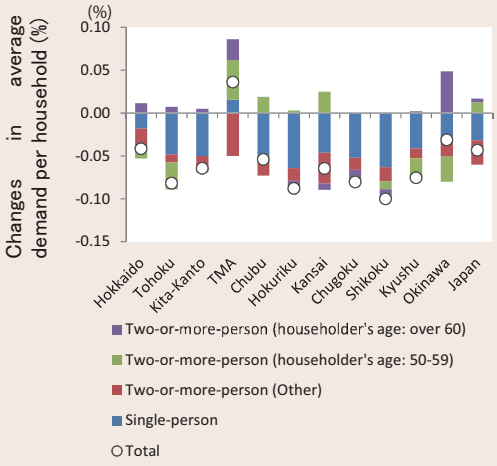


Fig. 1: Changes in average residential electricity demand per household during 2010-2030 (%)

Assuming constant electricity saving rates and electrification rates in the future, the change in household-types during 2010-2030 will decrease the average residential electricity demand per household by 0.04% per year in Japan, decreasing it in most regions (e.g. -0.10% in Shikoku), while increasing the average demand by 0.04% in the TMA.

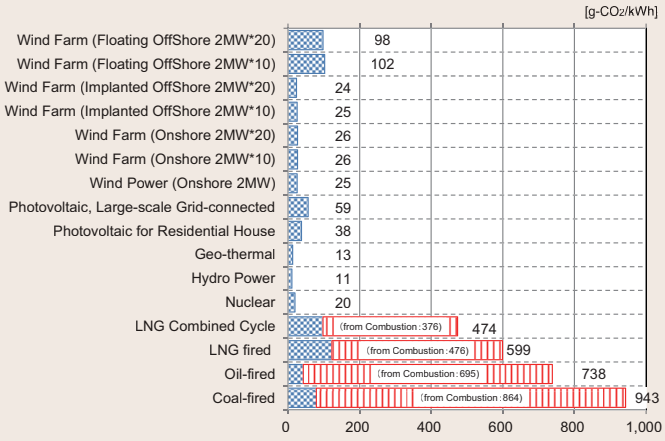


Fig. 2: The LC-CO_2 emission comparison on the 2009 standard

Since the 'floating offshore' wind farm employs a large floating body, the LC-CO_2 emissions were found to be 4 times greater than onshore and implanted offshore wind farms. These results concluded the LC-CO_2 emission assessment on the 2009 standard for all commercial generation technologies currently available.

Basic Technology Subjects

System Engineering Research Laboratory

Brief Overview

The System Engineering Research Laboratory (SERL) conducts research on the planning, operation, control of, as well as analysis methods for, electric power transmission, distribution systems, and information/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 the development, testing, and assessment of customer service technologies to achieve more efficient use of electricity.

Achievements by Research Theme

Electric Power Systems

We develop the fundamental techniques of transmission system analysis and evaluations, control and protection for economic and stable operation of the system. 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.

- High penetration of renewable energy sources could cause an increase in the frequency fluctuations and the shortage of control reserves. Therefore, a requirement arose for new models of thermal power plants (conventional steam power plants and combined cycle power plants) suited for balancing and frequency control analysis. In order to achieve this, the developed models[*1] are arranged to be manageable and generic reducing the size of the models and integrating various types of thermal power plants into two models. The developed models were validated through a comparison between the model response and the measured response of representative thermal power plants (R14018).
- Construction of frequency converters and HVDC transmission systems for wide-area interconnection has been planned to be carried out in Japan. The two novel control schemes for the HVDC system using the full bridge modular multilevel converter (MMC)[*2], which is suitable for improving the performance of the HVDC transmission system, have been developed. A full bridge MMC with the developed schemes enables continued operation during high voltage in AC grid and prompt starting which cannot be achieved using the conventional scheme (R14016).

Customer Systems

We develop a management technology targeting air conditioning for living environments and proposed a ventilation design criteria for commercial electric kitchens as energy conservation and load leveling assistive technology. In addition, we also developed a reasonable harmonic suppression method for maintaining power quality, an autonomous distributed control system of distributed energy systems.

- A heat source characteristic model to estimate the power consumption of air conditioners to achieve both energy saving and comfort was developed. This model can make estimations depending on the air temperature and airflow distribution of various room air conditioners (R09). With this model a tool was developed to facilitate the selection of a suitable type of air condition based on the user's various residential characteristics, lifestyle and selection rates of preference (R14010). The heat source characteristic model was incorporated into the CFD tool 'CADIEE-Airflow' and an examination was conducted into the accuracy calculation of the power consumption and temperature and airflow distribution of the air conditioner (R14005).
- The harmonics current generated from loading apparatuses connected to distribution lines causes voltage distortions and generally, since the fifth harmonic current is most influential, there is a need to develop a countermeasure technology. Therefore, by analyzing temporal transition of the fifth harmonic current, the phenomenon was found to be due to difference in load type composition (R14002). Furthermore, fifth harmonic currents were estimated for the load type composition for each area and the influences to the harmonic voltage by power factor correction capacitor etc. were shown (R14011).
- A community model for economic efficiency evaluation of an energy system in a demand area (community) was developed (Fig. 1). Using the community model, the benefit to the community operator under the present electric rate structures was calculated by annual simulation. One simulation result suggests that the operator can obtain a profit by installing cogeneration in the commercial area and also by utilizing exhaust heat (R14017).

Communication Systems

In order to secure high reliability of communication networks for power utilities required for operations and control of power systems, we develop disaster tolerance improvement technologies for communication systems, construction technologies for communications systems to assist restoration of damaged power systems and security technologies for SCADA systems.

■Incoming surge current from lightning through a waveguide is a problem in microwave radio equipment. We have been developing a system using optical fibers instead of waveguide to improve lightning protection performance. We have made a prototype of an outdoor type radio signal transmission unit. We have confirmed the transmitting and receiving of signals and power supply is possible by using optical fibers alone. Furthermore, we have evaluated communication characteristics using real radio equipment, and discovered that the signal quality was equivalent to the conventional system (R14006).

■A range (communication distance) to ensure a required transmission rate for voice and video applications by long-range multi-hop wireless LAN used for a temporary communication line between a manned site and a devastated area during a large-scale disaster was evaluated based on field measurement.

Furthermore, operations to be performed by field workers, such as adjustment of antenna direction and confirmation of received signal strength, were listed and a basic construction procedure for quick and reliable construction of temporary communication lines using long-range multi-hop wireless LAN was developed.

Mathematical Informatics

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

■Water wheels of hydroelectric power plants are renewed based on damage levels. Cavitation is one of the major causes of water wheel damage. Depths of cavitation damages on water wheels are measured with caliper gauges in current periodic inspections. To support the inspections, a depth measurement method of cavitation damages was proposed (Fig. 2). The method uses a small camera and a small laser module. It calculates depth of the cavitation damage by triangular surveying. Measurement errors of cavitation damages' depth were within 0.5 mm in water wheel inspections. The method is able to measure the depths of cavitation damages by simple operations more than caliper gauges.

*1 A dynamic model which is able to adequately represent the active power response to demand changes and frequency fluctuations (within about ±0.2Hz).
*2 MMC is a new type of converter which consists of semiconductor cells with cascaded connections. MMC is one of the promising converters and is expected to increase in capacity for application with higher voltage.

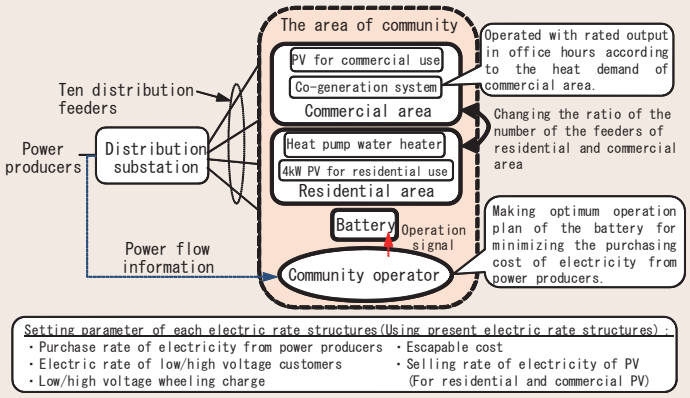


Fig. 1: Community evaluation model

By the supply and demand simulation of electric power and thermal energy considering economic operation of customer equipment (heat pump water heater, battery storage system) and community equipment (battery storage system, cogeneration), relationship between the configuration of community (PV installation ratio, ratio of residential and commercial area, capacity of battery storage system and cogeneration) and the benefit of the community operator can be analyzed.

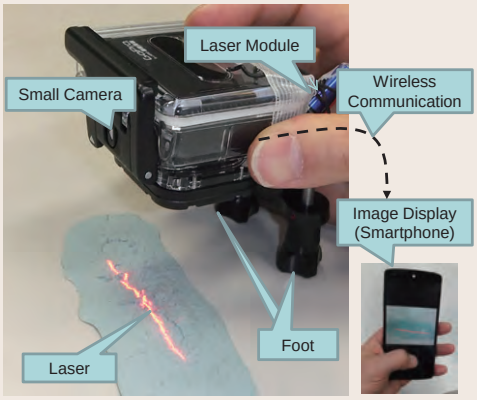


Fig. 2: Prototype of measurement system

Position of the laser projection line is moved in according with depth of the cavitation damage. A captured image by the small camera is displayed on the smartphone using wireless communication. A user can measure the depth of cavitation damage by the line position on the display which is drawn scale.

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 the recovery from the accident at the Fukushima Daiichi nuclear power plant, so that the use of nuclear energy may be accepted by society in a positive manner.

Achievements by Research Theme

Reactor Systems Safety Technology

In order to continuously improve the light water reactor safety, the development of measures to prevent and mitigate accidents is important in increasing the reliability of nuclear reactor system during operational and accidental conditions. To this end, we aim to sophisticate the evaluation system applied to thermal-hydraulics and risk assessment.

- The Filtered Containment Venting System (FCVS) is required as a severe accident mitigation measure of nuclear reactors. The experimental results showed sufficiently high iodine decontamination performance for a FCVS in operating range (Fig. 1).
- To clarify the reactor core cooling characteristics during a severe accident, a boiling two-phase flow experiment was conducted with a simulated fuel rod bundle. The boiling two-phase flow (e.g. bubble diameter and void fraction) acquired boiling two-phase data (bubble diameter, void fraction and so on), which was expressed as a function of radial power profile, inlet velocity and temperature for the quantitative prediction.
- Regarding the Bayesian methods developed in JANSI for the estimation of component failure rates using 26-year-event data and initiating event frequencies for Japanese nuclear power plants, we have devised a method to resolve the convergence problem in Monte Carlo calculation which arose for rare-event data. JANSI will use the devised method to update the domestic failure rates with 29-year-event data.
- The effect of droplets in wet steam on resonance frequency was investigated in order to evaluate the vibration fatigue of piping and components due to acoustic fluctuations of wet steam at a pipe branch of power plants. A theoretical analysis indicated that droplets in wet steam reduce the resonance frequency when steam wetness is more than several percentages and resonance frequency is less than several hundred hertz (L14006).

Nuclear Fuel and Reactor Core

For enhancing the safety of light water reactor fuel and core, research is promoted to determine the corrosion and degradation mechanisms of fuel cladding, understand the characteristics and behavior of fuel under accidental conditions, and improve the methods of core burnup performance analyses. Characterization of molten fuel and technology development for spent fuel subcriticality measurement are also continued for contributing to the decommissioning of the Fukushima Daiichi nuclear power plants.

- The residual stress distributions in the oxide films formed on fuel claddings were determined from diffractometry by using the X-ray microbeam at the synchrotron radiation facility, SPring-8. The result indicated that the oxide film with preferentially-oriented grains withstands high compressive stress, which presumably suppresses oxygen and hydrogen diffusion in the oxide and accordingly provides a good corrosion resistance. This suggests that controlling the oxide film grain structure is an effective way to improve the corrosion resistance of cladding materials.
- A computer code to simulate several phenomena in nuclear reactor severe accidents was developed based on a particle method, where an object is treated as a cluster of hypothetical particle. Models for heat transfer, surface tension, solidification and melting were developed and implemented in the new code. Further improvement in the code will enable the reasonable simulation of complicated phenomena, such as fuel melting and molten material relocation.
- The criticality safety design of spent fuel storage facilities can be rationalized by considering the reactivity decrement of spent fuel assemblies. This requires the confirmation of the burnup histories of respective spent fuel assemblies. For developing a method to confirm the burnup histories, the radioactivity ratios, $^{134}Cs/^{137}Cs$ and $^{154}Eu/^{137}Cs$, were evaluated from gamma-ray spectra measured for high burnup (approximately 56GWd/t) fuel rods. The evaluated values agreed with the radioactivity ratios obtained by the calculation tracing the burnup histories. This means that the method of using radioactivity ratios is applicable to high burnup spent fuels (L14003).

Nuclear Fuel Cycle

We contribute to closing the nuclear fuel cycle by conducting studies necessary for the early commencement of commercial

operation for Rokkasho Reprocessing Plant. Other studies for new additional facilities at the reprocessing plant are also conducted. A prevention technique for radioactive contamination during severe accidents and a treatment technique of damaged fuels by applying a pyrochemical technology are discussed.

- In order to obtain basic data necessary for safety analysis during storage of hull waste (chopped fuel pin), the vaporization behavior of water contained in crystallized zirconium molybdate (Mo-Zr) is estimated and the pressure increase in the container for the hull waste on which some Mo-Zr is adhered is evaluated. Vitrification tests of the incinerated ash are conducted as an example of application of vitrification technologies for the low level waste generated at nuclear power plants.
- We are continuing the technical support for the radioactive contaminated water treatment facility. For the purification of sea water contaminated with relatively low radioactive, we proposed the combined process of the zeolite absorption process, the zeolite regeneration process by elution and the precipitation method for the removal of radioactive elements effectively from seawater.

Human Factors Research

In order to contribute to building an organization that exhibits good performance free of 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.

- Through literature review and an interview survey on training/education methods to improve workers' risk perception, we categorized the methods into 10 categories and extracted 24 conditions needed to make the training/education successful. In particular, we identified that making trainees feel fear of risk/hazard, recognize gap between self-evaluation and reality and evaluate from others as the most important of the said 24 conditions. Educational effectiveness for their risk perception is expected to be increased by providing educations and trainings with consideration of these conditions.
- We proposed systematized measures for introducing safety rules in the process of developing corrective actions of an incident with consideration to the effect of level of rule detail on the psychological process of workers*. These measures enable restricting the number of excessively detailed rules introduced as corrective actions on a human factor incident.

* For example, while an excessively detailed rule leads to confidence towards the result of a safety behavior, it also supposedly leads to a decrease in work efficiency.

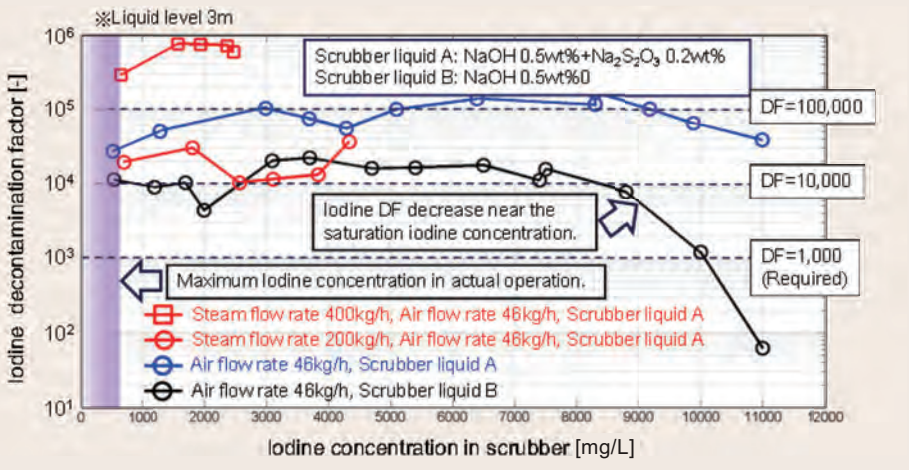


Fig. 1: Iodine decontamination performance

Iodine DF (vertical axis) with the full-height facility as a function of the iodine concentration in the scrubber (horizontal axis). Iodine concentration can be reduced less than 1/1000 with FCVS even beyond the operating range show in the left of the figure (iodine concentration range 0 – 600 mg/L).

Basic Technology Subjects

Civil Engineering Research Laboratory

Brief Overview

The Civil Engineering Research Laboratory extensively promotes studies into 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 as well as the asset management of 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.

- By using an X-ray CT scanner and scanning electron microscope, we developed a new approach in which we examine the fault activity based on whether fine minerals growing along the fault plane moved in the latest event are deformed or not.
- We analyzed displacements of surface faults located in the vicinity of a primary strike-slip fault using dynamic rupture simulation. This simulation enables us to evaluate surface displacements in an earthquake caused on a primary fault near a site (N14007).

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 analyzed the expected JMA (Japan Meteorological Agency) seismic intensity at each substation throughout the country within 100 years in order to assess the validity of the nationally unified seismic force level for substations. The results showed that the JMA seismic intensity is lower than 6-lower at about 90% of the substations and that the seismic intensity of 6-lower indicates the design level of substations. We conducted a statistical analysis of seismic force for seismic intensity of 6-lower based on the recent observation data and showed that the average acceleration response spectrum for the seismic intensity of 6-lower is comparable to the dynamic design seismic force of the existing guidelines.
- We applied the shaking table tests of center-clamp type bushings on transformers at high acceleration input motions. The results showed the non-linear behavior of the bushings and the extrusion of packing from the lower end of the bushings which causes continuous oil leak. In order to replicate the tests, we developed a new analysis method with a fiber model*1, which can evaluate non-linear response of the bushings (N14012).

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.

- As a part of the research toward the construction of the seismic damage evaluation method of reinforced concrete (RC) structures based on deformation indices, we conducted static loading tests using RC members under the low margin condition of shear strength and clarified the relationship between the lateral expansion of members after shear failure and the strength reduction[1] (Fig. 1). This means that the damage level of real structures can be derived from the measured lateral expansion after an earthquake.
- For the purpose of expanding the amount of fly ash used in concrete applications, we analyzed previous research focused on phase composition (types and ratio of materials) of the hardened cement paste with fly ash. As a result, we found that the concept of phase composition can be applied to the evaluation of physicochemical performance including strength. However previous research is limited from the viewpoint of variability in the quality of fly ash and various mix proportions. Therefore it is necessary to clarify the relationship of phase composition and performance for various conditions (N14014).

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 for the hydraulic and atmospheric fluid flows relevant to such facilities.

- We developed a method for obtaining appropriate unsteady wind velocity at an inlet boundary in wind simulations. Turbulence properties such as the turbulence length scale (the size of vortices in turbulence) that vary depending on weather conditions are controlled by the input parameters, and the conservation laws of flow dynamics are satisfied in the flows generated by using the method. This approach contributes to an improvement in reproducibility of complex actual wind, and can be applied to unsteady wind simulations for the wind resistant design and the evaluation of ash fall impacts for power facilities (N14011).
- We constructed a numerical simulation method for a natural convection boundary layer along a vertical heated plate. The simulation using this method elucidated the turbulent characteristics inherent in this boundary layer flow. The method enables accurate estimation of the heat transfer rate between the heated plate surface and ambient air, which will contribute to an evaluation for the fire-resistant capability of power plant facilities with precision (N14013).

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 and geothermal power generation.

- To support electric power utilities in order to address future introduction of regulations regarding application of CCS, we surveyed trends in technical developments and policies in Japan and around the world (N14005). The world's first CO_2 capture and storage commercial operation of a coal-fired plant began in Canada in 2014. The success of this project depended on establishing CO_2 emission regulations and selling CO_2 to the oil industry.
- We surveyed the present status of technology developments for Enhanced Geothermal System (EGS) which can contribute to the stable operation of geothermal power generation. We summarized the issues relating to these technologies to apply in various sites by dividing these technologies into three types, (i) artificial water injection into the natural reservoir to recharge water volume in the reservoir, (ii) permeability improvement by creating fractures in rocks in and around reservoirs, (iii) artificial reservoir creation (N14017). We will contribute to improving the versatility of EGS technology by solving these issues.

*1 A beam model of the Finite Element Method, which can evaluate non-linear behavior in the section subjected to axial force and bending moment.

[1] Y. Miyagawa et al., JCSE Jour. E2, Vol.70, No.4, pp.402-416 (2014).

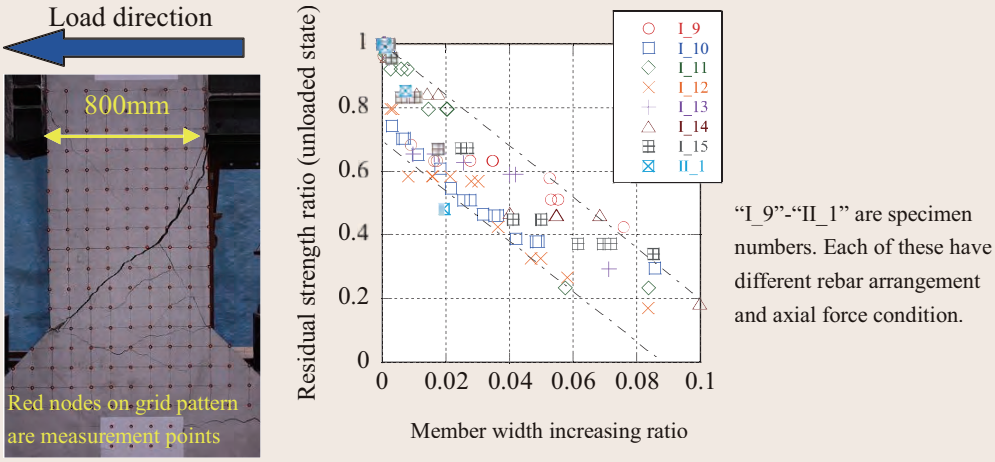


Fig. 1: Relationship between the lateral expansion of RC members and strength reduction

The apparent increase of member width caused by widening of inclined cracks was measured using image measurement (left picture). One plot of the right graph corresponds to a picture in a certain point of time during the loading and the marker was distinguished with the specimen. It was found that both indices were highly correlated.

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, and chemistry, 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 research objectives are to develop technologies for predicting and assessing atmospheric and marine environments in order to deal with environmental problems associated with nuclear power plants, such as air pollution and the marine dispersion of radioactive materials.

■A numerical fluid dynamic model that can simulate the dispersion of emission gas in a stable atmosphere using thermal stratification was developed to assess the effects of atmospheric stability*1 on the dispersion of emission gas in the vicinity of reactor buildings of a nuclear power plant. The developed model enables the prediction of the dispersion of emission gas in a strongly stable atmosphere in a shorter time and at a lower cost than wind tunnel experiments.

■A biogeochemical process was incorporated into our high-resolution regional ocean model on the scale of the North Pacific Ocean to assess the marine dispersion of radioactive nuclides that easily adsorb onto biogenic particles. The new model reproduces the role of phytoplankton and enables the accurate assessment of the sedimentation behavior of radioactive materials (V14009).

River and Coastal Environment

The research objectives are to develop technologies for monitoring, predicting, and assessing inland and coastal water environments in order to solve problems related to electric power utility. These environments include rivers and reservoirs affected by hydraulic power plants, as well as coastal environments near thermal and nuclear power plants.

■A method for analyzing the coastal current pattern and its frequency was developed by combining SOM (Self-Organizing Map)*2 with flow observation using ocean radars. This method reduces the number of observation points with a conventional velocimeter, and is expected to cut down the cost of oceanic observation in the environmental impact assessment of coastal power plants (V14015).

■The purpose of this research is to develop a tool for the comprehensive assessment of river environments that can be used for updating water rights and supporting sediment throwing in hydropower dams. A method for assessing the primary productivity of algae that is a key indicator of river ecosystem health, was developed by continuously monitoring the dissolved oxygen (DO) concentration in river water (V14011).

Biological Environment

The research objectives are to develop technologies for addressing problems related to biofouling and jellyfish and for preventing accidents at power facilities caused by birds and mammals, and thus contribute to realizing a stable power supply and its effective maintenance. Biological effects of power- and intermediate-frequency magnetic fields are also examined to increase the general public's understanding of their possible human health risks.

■Short-circuit accidents may be caused by birds and mammals that come in contact with transmission and distribution wires and enter substations. The research team developed a technique for specifying species of birds and mammals through the DNA analysis of feces and feathers left at accident sites as well as a technique for detecting birds by videography at night as well as day. These techniques can be used to prevent accidents in accordance with the type and behavioral characteristics of the animal (R14015).

■Golden mussel, an invasive adhesive bivalve, causes clogging of water supply pipes at hydraulic power plants. Our research team investigated control measures for this species conducted at overseas electric power plants and developed antifouling methods using ozone and a copper alloy strainer. The selection of optimal antifouling methods for each power plant based on this knowledge can contribute to preventing problems caused by the adhesion of bivalves and reducing the amount of organic waste which occurs at a regular cleaning (V14010).

Bioengineering

The research objectives are to develop technologies related to the economic treatment of transformers contaminated with trace polychlorinated biphenyls (PCBs), to the advanced utilization of unused carbon resources, and to the agricultural application of heat pumps.

■The research team formulated guidelines on the circulative cleaning technologies for transformers contaminated with trace PCBs. The guidelines can be commonly applied to various companies involved in power generation and used to specify the technical items, such as the environmental assessment and the determination of cleaning conditions, required to apply for permission from the Ministry of Environment to install treatment facilities.

■A pellet mixture of lignite (a low-quality coal) and biomass residues (rice bran, Jatropha oil cake, and eucalyptus chips) was prepared and its fuel characteristics were assessed with the aim of increasing the effectiveness of lignite. For a mixture of lignite and rice bran with a percentage of lignite of up to 50%, high formability and heat generation were achieved (V14008).

Environmental Chemistry

The research objective is to develop low-cost technologies for the management and treatment of trace chemical substances, such as selenium in wastewater from coal-fired power plants, in order to support the high-performance and stable operation of coal-fired power plants. The effects and suitability of environment-related measures are assessed to reduce the environmental risks associated with thermal power plants.

■A biochemical treatment method involving a reduction process using microorganisms was developed for selenium in desulfurization wastewater from coal-fired power plants (Fig. 1). An on-site test using a small system demonstrated that the concentration of selenium in wastewater from a power plant could be reduced to lower than the regulation value (Fig. 2). The developed method is expected to reduce the costs of chemicals and the treatment of sludge to approximately half and one-tenth of those required for the conventional chemical treatment, respectively

■Nitrogen-sulfur (NS) compounds cause an increase in chemical oxygen demand and total nitrogen concentration, which are indices for the degree of pollution of wastewater from thermal power plants. An analysis technique for NS compounds was established towards their detection and quantification. The technique was confirmed to be useful for specifying NS compounds that cannot be removed by existing wastewater treatment facilities at coal-fired power plants (V14002).

*1 An index relating to the ease with which the atmosphere moves in the vertical direction. In general, emission gas is less dispersed in a strongly stable atmosphere.
*2 A type of neural network and multivariate analysis method that enables the pattern classification of multidimensional data through unsupervised learning.

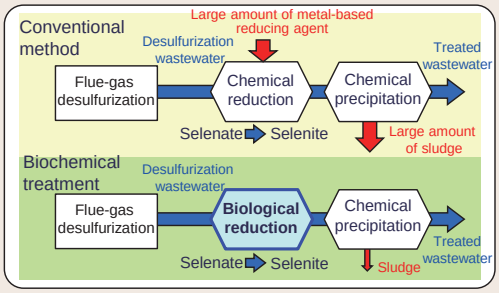


Fig. 1: Treatment process for selenium in wastewater from a coal-fired power plant

Conventional chemical treatment process (upper) and biochemical treatment process (lower). The conventional treatment process consists of two steps: (1) Selenate reduction through the addition of a metal-based reducing agent and (2) Chemical precipitation for selenite. The high costs of the reducing agent and the treatment of the resulting sludge were issues to be addressed.

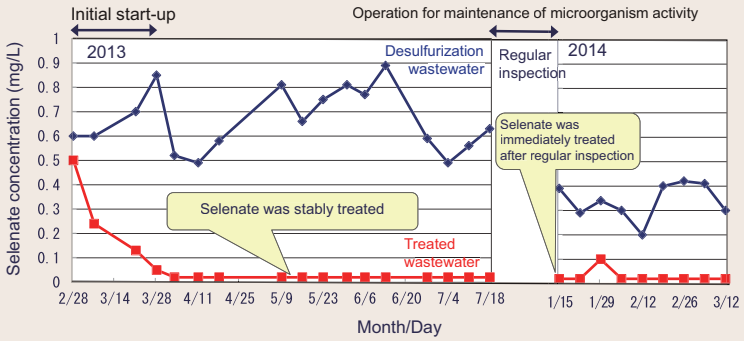


Fig. 2: Bioreactor for selenium reduction (left) and selenium treatment in on-site test at coal-fired power plant (right)

It took approximately one month for the acclimation of microorganisms at initial start-up. Afterwards, selenate was stably treated. Selenate was immediately treated after regular inspection (on January 15 and later).

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 high voltage technology, electrical insulation, lightning protection, electromagnetic environment and high current technology for power transmission and distribution equipment. It is also developing next-generation power equipment and XTAP (eXpandable Transient Analysis Program), simulation and application of arc, application of power electronics and lasers.

Achievements by Research Theme

High-voltage and Insulation

We aim to clarify the deterioration mechanism of solid type 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.

■We applied the residual charge method with pulse voltages to removed cross-linked polyethylene (XLPE) cables of the 60 kV class. The relationship between duration of degradation signal and AC breakdown voltage was clarified and the applicability of the method to 22 to 77 kV XLPE cables was confirmed.

■We applied condition assessment methods using SF_6 decomposition gases to actual gas insulated switchgears (gas section of gas filled bushing, disconnector, and bus-bar), and confirmed the applicability as fault detection method.

Lightning and Electromagnetic Environment

We aim to develop new technologies for lightning protection and insulation coordination that are applicable to the demand and supply system of electricity and energy in an information-communications technology (ICT) society. We also aim to establish the technologies for assessing the electromagnetic compatibility (EMC) and electromagnetic environment in power systems and consumer equipment.

■For the development of a new type of LLS (Lightning Location System) with the aim of establishing the lightning protection design with high accuracy for power systems and creating a method to efficiently detect lightning fault locations, we theoretically investigated and identified the cause of detection errors in the current LLS. As a result, it became clear that optimization of the sensor spacing enables creation of new LLS which is equipped with an acceptable detection error range of several-dozens meters (H14007).

■For the development of lightning protection measures for smart meters, the lightning performance of electronic watt-hour meters having a function equivalent to smart meters was evaluated with the lightning impulse tests. As a result, it became clear that lightning performance varies depending on the internal structure of electronic watt-hour meters. Based on the results obtained from the lightning impulse tests, we proposed a method for calculating the lightning failure rate of electronic watt-hour meters (Fig. 1). We suppose that a guidebook of lightning protection design for smart meters will be created in the near future (H14009).

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 to develop 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.

■Cost reduction of Fault Current Interrupting Arcing Horns (FCIAH) was achieved by reducing the number of interruption cores from the present two to one, through computational fluid dynamics to calculate the pressure distribution in the interruption core and a nozzle design to generate a supersonic flow. Moreover, strength enhancement of FCIAH was realized by appending pressure relief holes to suppress the pressure rise in the interruption core due to the arc heat (Fig. 2) (H14001).

■A portable system for nondestructive detection of the thermally grown oxide layer, which is a cause of topcoat delamination in thermal barrier coating (TBC) for gas turbines, was developed. Using this system, TBC specimens heated in the air were measured and emission, which is thought to result from high concentration of Cr^{3+}, was observed. This result showed the possibility of evaluating regions of the TGO layer with high Cr^{3+} concentration (H14006).

Electric Power Application

We aim to develop analysis methods for electric power quality and technologies for the design and management of

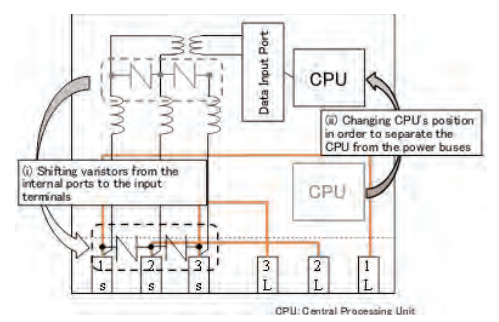
reasonable electric power systems connected via power electric equipment by developing cooperating technologies together with customers for improving electric power quality.

- A frequency-dependent line model for electromagnetic transient (EMT) simulations based on the FDTD (Finite Difference Time Domain) method has been developed. This model does not require modal decomposition and has excellent numerical stability (H14013).
- An electromagnetic transient (EMT) simulation model of STATCOMs for distribution systems has been developed as countermeasure for the problem of voltage rise due to the spread of renewable energy. This model enables a dynamic voltage analysis which considered switching of power electronics equipment (H14014).

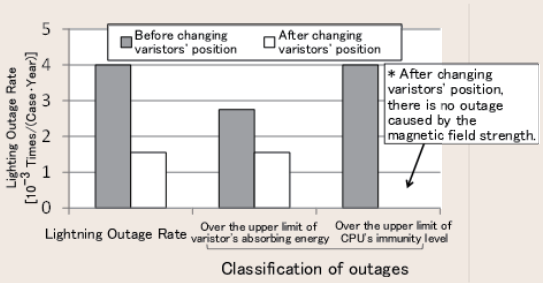
High Current Technology

To estimate the performance of electric equipment upon a short-circuit fault, we aim to improve short-circuit test techniques and establish measuring techniques for power frequency current.

- We investigated the fault conditions for which the rate of rise of recovery voltage on current interruption in power systems in Japan exceeds the values in JEC2300, the standard for high-voltage alternating-current circuit-breakers (CB), and clarified the range which the high power short-circuit test facilities of CRIEPI can verify the current interruption performance of CBs.



(a) Lightning protection measures using the position change of internal elements



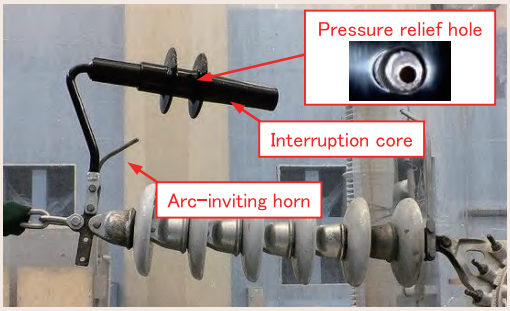
(b) Evaluation of lightning outage rate for electronic watt-hour meters

Fig. 1: Lightning protection measures for electronic watt-hour meters and their evaluation results

We developed a calculation method of the lightning outage rate for these meters. In the calculation method, the lightning outage rate is calculated with the threshold of the lightning fault occurrence of meters obtained from the experiment. With the calculation method, we calculated the lightning outage rate of meters. Based on the results, we evaluated which lightning protection measure is most effective. As a result, the following became clear:

(i) Shifting varistors from the internal ports to the input terminals is effective for reducing the lightning outage rate of meters.

(ii) Changing the CPU's position to separate the CPU from the power buses is also effective for reducing the lightning outage rate of meters.



Breaking current and its iteration	Up to 7 kA three times
Current breaking time	Within an AC cycle
Explosion-proof current (*)	Up to 15 kA

(*) Maximum current which does not cause damage of the interruption core.

Fig. 2: High-strength type Fault Current Interrupting Arcing Horns for 77 kV overhead transmission lines

Strength enhancement of Fault Current Interrupting Arcing Horns was realized by increasing the explosion-proof current from the present 10 kA to 15 kA, through the installation of pressure relief holes to suppress the pressure rise in the interruption core due to the arc heat and an arc-inviting horn to reduce the damage to the interruption core by moving an arc generated by an excessive fault from the inside of the interruption core to the outside.

Basic Technology Subjects

Energy Engineering Research Laboratory

Brief Overview

The Energy Engineering Research Laboratory is aiming to achieve security, as well as construct power and energy supply and demand systems, through the 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 secure the reliability and decrease the operation and maintenance costs of thermal power plants, the rationalization of maintenance and management for the boiler tube and the gas turbine hot gas path parts, as well as evaluation technology of applicability of non-conventional liquid fuel to the thermal power plant are under development. In order to improve efficiency and reduce carbon emissions, we aim to support the smooth introduction of IGCC commercial plants and to evaluate a next-generation coal-based thermal power plant system.

- The creep damage of boiler tubes was evaluated to be negligible by the results of a creep test and metal temperature analysis of boiler tubes in pulverized coal fired power plant boilers which adopted Combined Water Treatment. These tests also suggested that the extension of chemical cleaning interval of boilers was possible.
- The applicability of the eddy current testing method, which is a form of nondestructive testing for a base metal surface cracking of thermal barrier coatings of gas turbine blades, was revealed. Furthermore, the nondestructive testing methods, including the eddy current testing, which contribute to determination of the extension of TBC recoating interval, were established by devising an effective testing flow for multiple damages and degradations such as cracking and recession of TBC blades (M14006).
- The deterioration behaviors of biomass liquid fuel in storage, which is one of the solutions to reduce CO_2 emissions intensity, was evaluated. Molecular weight spectrum was suggested as an indicator for deterioration such as the increase in viscosity and precipitation of solid matter, which could not be evaluated by conventional indicators (M14005).
- CRIEPI has developed a high-efficiency Oxy-fuel IGCC system, anticipated as one of future technologies to reduce CO_2 emission. In 2014, a heat and mass balance analysis was executed and the results showed that the system can maintain efficiency at over 43% even with CO_2 capturing, supposing three different brands of imported coal, namely, Indonesian coal, Chinese coal and Australian coal*1.

Advanced Fuel Utilization

For the diversification of energy resources and the improvement of environmental friendliness of coal-fired power plants, combustion enhancement methods of a low combustibility coal, countermeasures for the spontaneous ignition of solid fuels, dewatering methods of brown coal, measurement methods for trace elements, countermeasures for clinker in boilers, manufacturing methods of fly ash solidification material and the evaluation method for coal utilization are under development.

- TIn order to clarify the issues surrounding coal ignition in mills, we interviewed pulverized coal-fired power plant staff about recent accidents, their causes and the related preventive measures. The results showed that ignition in mills was mainly caused by self-heating of locally deposited pulverized coal. In addition, the factors influencing ignition in mills and explosion of suspended pulverized coal were investigated on the basis of literature research.
- To increase the utilization amount of coal fly ash (FA), the production condition of FA-shell solidification material without the use of cement and heat treatment was clarified. In the production process, FA, unburned pulverized shell, gypsum and lime as raw materials were mixed with kneading water and casted with vibrating to obtain high compressive strength with depressing large pore. A solidification material which has the same material strength to the granular solidification material that has already been in practical use, was produced by adjusting the frequency of vibration and the suitable proportion of FA and shell. Furthermore, it was confirmed that the trace elements leaching from the material of 1-2 mm in diameter was lower than the environmental standards at an age of 28-days.

Heat Pump and Thermal Storage

For developing high-efficiency heat pumps and expanding their application areas, we seek and evaluate innovative technologies. To assist in proposing energy-saving solutions to customers, we develop a simulation tool for analyzing their energy consumption.

- Regarding the proposed frost-free air-source heat pump system, we experimentally investigated the heat and mass transfer characteristics of the solid desiccant coated heat exchanger (SDCHE), and carried out a trial design to determine the layout and dimensions of the heat pump unit. The results revealed that it is possible to productize the proposed system at almost the same sizes as existing Eco-cutes, when the SDCHE

and the evaporator are laid out in the upper and down sides of one case (Fig. 1) (M14004).

■We improved the customer energy consumption analysis tool to evaluate the load leveling effect for a large number of customers. By analyzing the actual load data of the heat storage system, we quantitatively demonstrated the effect of maximum power reduction and power load leveling.

Energy Conversion Engineering

Basic technologies that relate to the evaluation of thermal efficiency and fuel cells, and environmental analysis, etc., will be developed to improve operability and thermal efficiency of the thermal power plants and geothermal power plants.

■Improving the efficiency of oxygen production facilities should bring about high thermal efficiency and reduction of CO_2 emission in coal-based power generation such as Integrated coal Gasification Combined Cycle (IGCC) power generation and pulverized coal oxy-fuel combustion power generation. Research into the development trend of high efficient oxygen production technology revealed that the cryogenic distillation method with heat integrated distillation column and the high temperature oxygen transport membrane method are highly applicable to coal-based power generation (M14010).

■Load-variation tests that involve a periodic current fluctuation test for 0.02-60 sec to a bench-scale Solid Oxide Fuel Cell (SOFC) have been carried out to explore the possibility of SOFC power systems toward dynamic operation for compensating power fluctuations of renewable energy sources such as photovoltaic and wind power generation. The results show that power response of SOFC is able to increase up to 125% in 2 seconds without increasing the amount of fuel fed into the cell (M14007).

■An electrode polarization model has been developed to evaluate SOFC cell performance under the pressurized conditions simulated SOFC triple-combined cycle system and the distribution performance of gas flow within the SOFC cell. Thus, an efficient performance improvement in SOFC gas channel can be expected (M14009).

Innovative Numerical Simulation Technology

A comprehensive numerical simulation tool is being developed by integrating multi-scale and multi-physical numerical schemes and models in order to solve issues taking place in thermal power generation plants by accurately evaluating performance and optimizing the operating conditions of thermal equipment, such as pulverized coal combustion boilers, coal gasifiers, and gas turbines.

■Towards the establishment of a combustion characteristics evaluation method for coal-fired boilers, a determination method of swirling flow condition for each burner based on plant operation data and local numerical simulation of a burner was developed. Moreover, in order to improve the accuracy of radiant heat transfer in the numerical analysis of pulverized coal combustion, a soot prediction model with high-accuracy and low-computational cost was developed by reducing enormous chemical species and reaction paths using the reaction reduction method.

*1 This work was commissioned by NEDO (New Energy and Industrial Technology Development Organization).

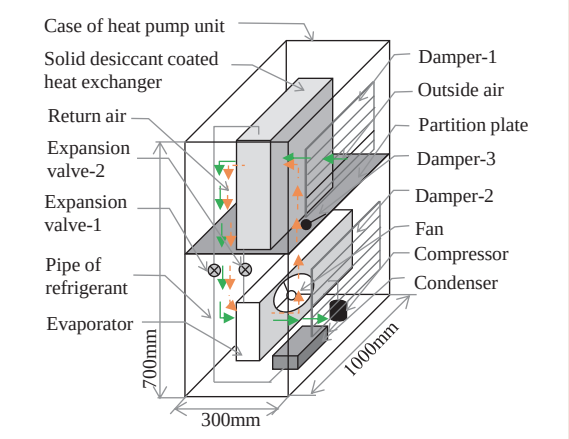


Fig. 1: Structure of a frost-free heat pump unit

●When in adsorption mode, expansion valves -1, 2 are throttled, dampers -1, 2 are opened and damper -3 is closed. Frosting of the evaporator can be suppressed because the outside air is dehumidified at the SDCHE. Hot water is produced at the condenser.

●When in desorption mode, expansion valve-1 is opened and expansion valve-2 throttled, damper-3 is opened and dampers-1, 2 are closed. The condensation heat of the refrigerant is used to produce hot water and regenerate the desiccant. A high system performance is obtained due to the recycling air flow between the SDCHE and the evaporator.

Basic Technology Subjects

Materials Science Research Laboratory

Brief Overview

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

Achievements by Research Theme

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.

- Creep strain equations have been developed in collaboration with the Electric Power Research Institute (EPRI), for Grade 92 steel, which is being progressively employed in newly built USC plants as a modified version of 9Cr steels. These equations provided a way to estimate progress of creep deformation as well as accompanying damage accurately, only from the creep rupture data of each product[1].
- The effect of periodical gas composition fluctuation in atmosphere on the sulfidation of water-wall tube made of low-alloy steels (STBA20, STBA22 and STBA24) has been clarified through corrosion tests conducted by periodically switching gas feed conditions between sulfidizing and oxidizing atmosphere. A technique for quickly and non-destructively identifying sulfidized areas on water-wall tubes has been applied to some commercial boilers, and sulfidized areas and tube thinning areas have been detected in some thermal power plants (Fig. 1).

Advanced Functional Materials

We will develop new functional materials (such as high-temperature superconductors, organic semiconductors, and ionic liquids) and will extend their application fields by utilizing various sophisticated techniques of growing and characterizing the materials.

- We improved growth techniques of iron-chalcogenide superconductors, and succeeded in raising superconducting critical temperature from 8 K to 12 K in FeSe thin films, and 14.2 K to 19 K in $FeSe_{0.5}Te_{0.5}$ thin films[2]. These films also exhibited extremely high critical current density at a high-magnetic field, and are anticipated as one of the candidates of practical superconducting coated conductor materials.
- We developed a new kind of organic device called a light-emitting electrochemical cell, and succeeded in preparing three basic colors, red, green, and blue (RGB), that are indispensable for display applications. These devices also exhibited a refreshing effect by current alternation, which is one of the key technologies for long-term stability

High Performance SiC Semiconductor for Power Electronics

To realize next generation low-loss power conversion equipment, we will establish a high-quality silicon carbide (SiC) crystal growth technology which enables the fabrication of low-loss, high-voltage, SiC power devices able to handle large currents.

- We developed production technology for high-quality SiC crystal films (epilayers) applicable to high-voltage and low-loss power semiconductor devices by engaging in collaborative development with several companies and established a crystal growth technique which obtained stable low defect density and highly uniform SiC crystal film with a high production rate on a 6-inch diameter substrate.
- We attempted to increase the growth rates in SiC bulk crystals and achieved crystal growth of SiC at a rate of 2.1 mm/h, which largely exceeded that of the conventional growth technique (sublimation method), maintaining quality equivalent to the high-quality seed crystal[3].
- Towards the reduction of defects (dislocations) in SiC crystals, we accomplished three-dimensional imaging of dislocations in SiC using a non-destructive optical method (two-photon-excited photoluminescence*1) (Fig. 2)[4] and by controlling the propagation direction of the dislocations by growing a SiC layer on a patterned substrate[5].

Materials Science Research Fundamentals

By integrating our fundamental technologies on computer simulations and advanced material analysis, we will promote

Achievements by Research Theme

the development of a multi-scale material strength evaluation method, and the development of metallographic change for high chromium steels.

- The nano-structure of high chromium steels was analyzed using a UV laser atom probe*2, and the distributions of nano-scale precipitates and trace carbon were disclosed.
- A finite element analysis code for crystal plasticity was developed. The increase of plastic strain due to creep deformation could be reproduced by simulating the collapse of lath structures*3, which was a typical degradation mechanism for high chromium steels.

*1 Luminescence created by electrons excited to a level double that of the incident beam energy by the simultaneous absorption of two photons.
*2 The pulsed UV laser enables atom probe measurement of high chromium steels, as it achieves efficient field evaporation.
*3 High density of dislocation in lath martensitic structure is one of the causes of high creep strength in high chromium steels. The collapse of the lath structures (decrease of dislocation density) is considered to cause the decrease in creep strength.

[1] H. Shigeyama et al., Proc. the 52nd Symposium on Strength of Materials at High Temperature, Hakodate, 2014.
[2] I. Tsukada et al., Jpn. J. Appl. Phys. 54, 043102, 2015.
[3] N. Hoshino et al., Appl. Phys. Express 7, 065502, 2014.
[4] R. Tanuma et al., Appl. Phys. Express 7, 121303, 2014.
[5] H. Tsuchida et al., J. Cryst. Growth 402, 260, 2014.

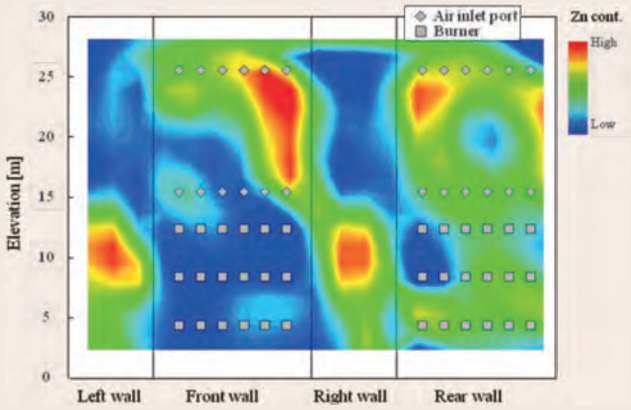


Fig. 1: Distribution of Zn content in the ash on the water-wall tube surface in a coal-fired boiler

Severe sulfidation occurs in areas where coal ash deposits contain a comparatively high Zn content. Sulfidation in the entire region of commercial boilers can be easily detected without descaling and within several hours by the use of a handheld X-ray fluorescence analyzer.

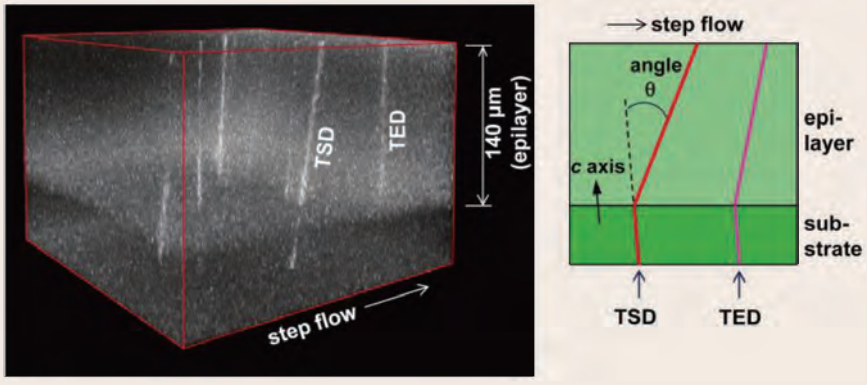


Fig. 2: Three-dimensional image of threading screw dislocations (TSDs) and threading edge dislocations (TEDs) in the SiC epilayer obtained by two-photon-excited photoluminescence

Propagation of threading and edge dislocations making an inclination angle throughout a SiC epilayer is visualized in three dimensions.

3. Major New Research Facilities

Renewal of the Generator Simulator of CRIEPI's Power System Simulator

Background

CRIEPI's Power System Simulator is a large analog simulator comprising components that simulate large generators, transmission lines and other power system components. It is capable of simulating generator responses and system-level phenomena that can occur after a system fault such as a lightning strike, and is useful for studying such phenomena and for developing and verifying countermeasure technology. As important parts of this simulator, we have renewed the unit control panel and generator operation panel of the simulated nuclear power plant unit (hereafter "nuclear unit") and the full set of the simulated thermal power plant unit (hereafter "thermal unit").

Outline

The nuclear unit and the thermal unit are equipped with a frequency control system (speed governor), and also with ΔP input type and ΔP+Δω input type power system stabilizers (PSS) that control power swing using signals of the active power deviation (ΔP) and the generator rotating speed deviation (Δω). Moreover, the nuclear unit is equipped with a multi-input PSS that surpasses the above-mentioned PSS in its capability to suppress long term swings.

Specifications

- Common specifications
  Rated terminal voltage: 220 V, Rated frequency: 50 or 60 Hz, Automatic synchronous parallelization apparatus: Speed governor (thermal unit), ΔP input type: PSS, ΔP+Δω input type: PSS
- Nuclear No.1 and 2 Unit
  Rated capacity: 100 kVA, Rated output: 90 kW,
  Multi-input MPSS, Speed governor (hydro, diesel, combined cycle), Plant control simulator (thermal, combined cycle),
  Step-out detecting relay, Cross current compensator
- Thermal No.4 Unit
  Rated capacity: 60 kVA, Rated output: 54 kW
- Thermal No.5 Unit
  Rated capacity: 90 kVA, Rated output: 81 kW

Nuclear unit control panel

[Location and date of installation]
Koma area / Feb. 2014 (Nuclear Unit),
March 2015 (Thermal Unit) / System Engineering Research Laboratory

The full set of the thermal No.4 and 5 unit

Generator operation panels

Experimental Facility for Simulated Rod Bundle Cooling of Light-water Nuclear Reactors

Background

In response to Fukushima Daiichi nuclear power plant accident, it is necessary to improve the safety measures for the reactor core damage prevention in the case of severe accidents (SA) beyond the design-based phenomenon required by the previous safety review. In the safety assessment of a nuclear power plant, it is important to evaluate the severe accident analysis under tougher conditions and to enhance accident management (AM) measures to prevent the SA. A large-scale experimental facility to visualize the detailed nuclear reactor thermal hydraulics is installed to advance the SA analysis code and AM measures.

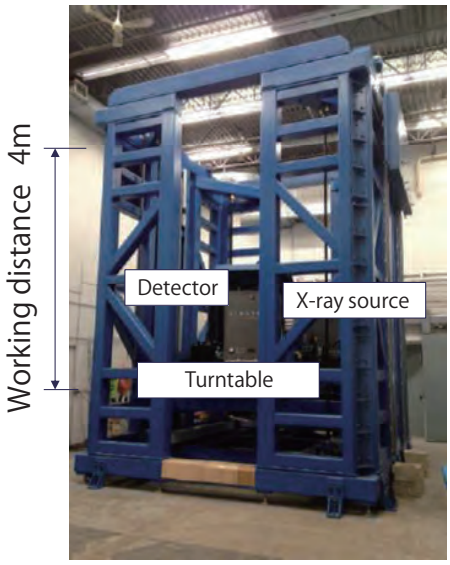
Outline

The experimental facility consists of a test loop to simulate the nuclear reactor thermal hydraulics and an X-ray computed tomography (CT) / real-time radiography (RTR) system to visualize a boiling two-phase flow distribution. The test loop can operate under high-pressure high-temperature conditions corresponding to rated operation in a boiling light-water reactor (BWR). The X-ray CT/RTR system has a function to take three-dimensional CT images of fuel rod bundles and thermal hydraulics in the pressure vessel and to record transmission images of a vapor-bubble and liquid-film behavior at a high-sampling rate.

Specifications

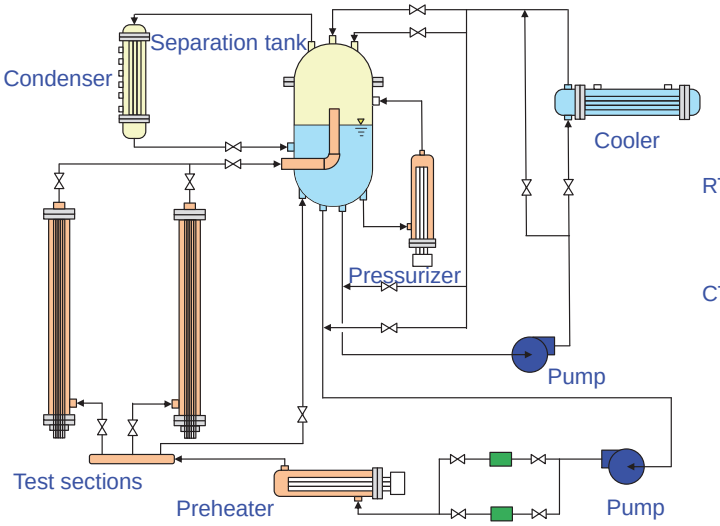
Thermal hydraulic test loop
- Maximum system pressure: 9 MPa
- Maximum system temperature: 305℃
- Maximum flow rate : 24 m^3/h

X-ray CT/RTR system
- X-ray source: High-energy linear electron accelerator
- Maximum field of view: 700 mm in diameter
- Working distance: 4 m in height

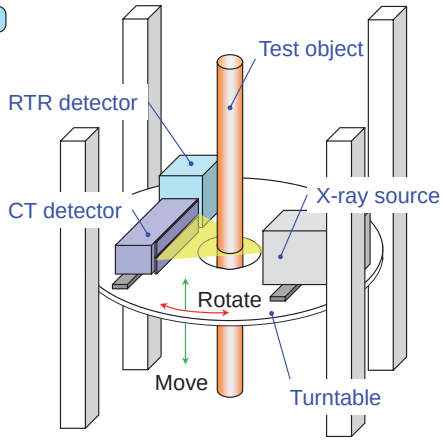


[Location and date of installation]

Yokosuka area / October, 2014



Thermal hydraulic test loop



X-ray CT/RTR system

Strong Shake Generator

Background

In order to improve the earthquake resistance of nuclear power plants (NPP), it is necessary to confirm the seismic safety of important structure, system and components under intense vibration. In particular, important active components for the protection of NPP safety function, such as the main steam safety-relief valve and various motor-operated valves, must be confirmed under ultimate seismic conditions by shaking table tests. However there are limitations of conventional shaking table capacity, for which maximum acceleration is less than 10 G (G: gravitational acceleration). Therefore a new shaking table system with a capability exceeding that of a conventional shaking table must be introduced to evaluate the earthquake resistance of important components.

Outline

The Strong Shake Generator (SSG) is a new shaking table facility amplifying vibration using a resonance phenomenon. The main characteristic of this facility, a shaking test of the world maximum acceleration 20 G is possible. This high acceleration shaking test could be realized by a double spring structure where the base of the resonance table is set outside the primary shaking table. Two sets of Semi-Active Mass Damper (SAMD) are also introduced to provide a vibration countermeasure method for the facility foundation.

Specifications

Table 1: Specification of Strong Shake Generator in comparison with the existing shaking table

Dimension	SSG	Existing shaking table
Operating Freq.	10Hz	DC～50Hz
Max. Acc.	20G	2G
Max. Load	10t	60t
Table size	2m×2m	5m×5m
Load direction	One horizontal axis	One horizontal axis

[Location and date of installation]

Abiko area / February 2015

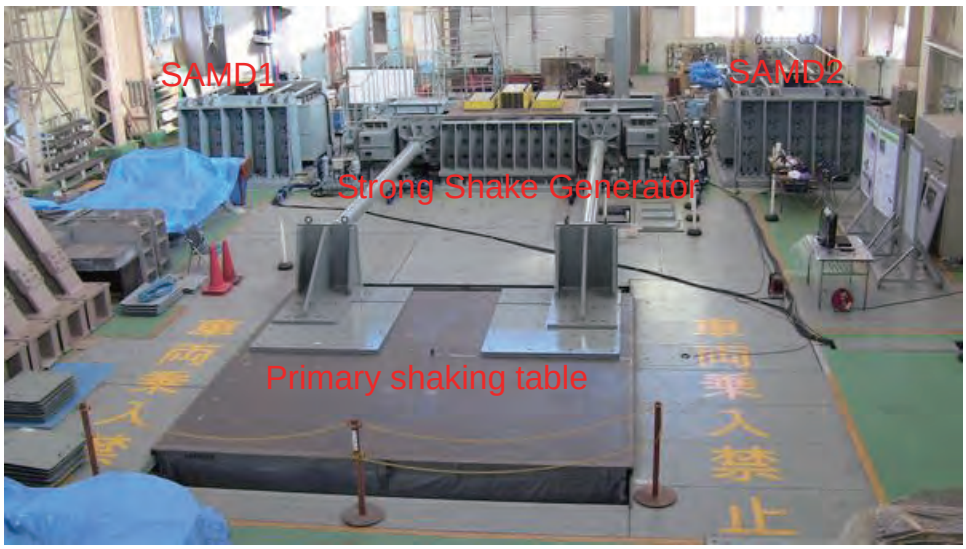


Fig. 1: Photo of Strong Shake Generator

Dynamic Geotechnical Centrifuge (unidirectional shaking table)

Background

Safety reviews of nuclear power facilities in accordance with the new regulatory requirements are being carried out by the Nuclear Regulation Authority (NRA), Japan. The NRA requires the determination of highly accurate design basis seismic ground motion and three-dimensional evaluations of the subsurface structure beneath the sites in the design of S-class buildings and structures, classified according to importance of seismic design. Furthermore, periodic safety reviews for NPPs are also required after NPPs recommence their operations. The NRA requires these periodic safety reviews to induce probabilistic risk assessment for NPPs, and this involves assessing the health of NPPs and their respective foundation ground. In order to meet those requirements, the development of two numerical analyses is urgently needed. One is a non-linear time history response analysis evaluating a failure zone and residual deformation of the ground. The other is a distinct element method assuming rock mass collision and rebinding during a slope collapse. The NRA requires verification of these new analyses methods through experiment. To carry out the verification test, CRIEPI has installed a Dynamic Geotechnical Centrifuge. On the basis of the scaling lows of centrifugal force field, the seismic behavior of the model is identical to that of the prototype.

Outline

This facility is composed of a unidirectional shaking table, a container with specimen, and dynamic data loggers, which are placed on the platform of a Static Geotechnical Centrifuge (facility name; Geotechnical Centrifuge System "CENTURY5000-THM") installed in 2009. For example, shake table tests of maximum ground acceleration form 500 gal to 1000 gal (the frequency of about 0.4~8 Hz) can be performed for 1/25~1/50-scale model of the ground. The dimension of the shaking table is 30 cm × 70 cm.

Specifications

[Location and date of installation]

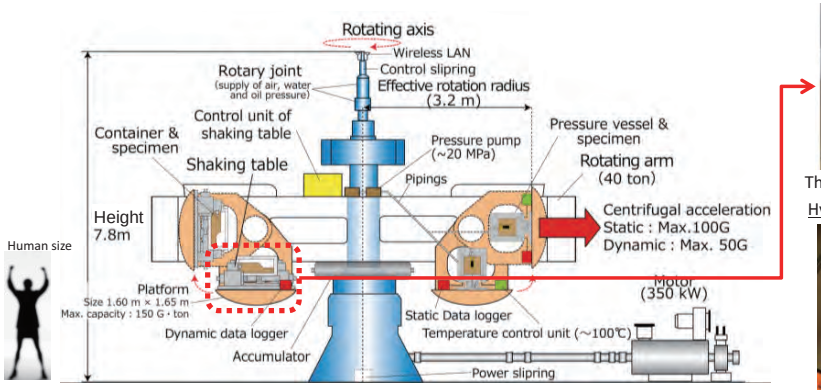
Abiko area / February 2015

Table 1: Specifications of Shaking Table

Shaking direction	Horizontal
Centrifugal acceleration	25-50G
Max. shaking acceleration	±35G
Max. shaking velocity	±80cm/s
Frequency range	10-400Hz
Wave shape	Seismic wave, sine wave
Dimension of shaking table	30 × 70cm

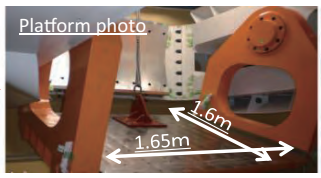
Table 2: Scaling Laws for 50 G Centrifuge Test

Physical property	Full-scale	Model
Size	1	1/50
Stress	1	1
Strain	1	1
Time	1	1/50
Acceleration	1	50
Frequency	1	50

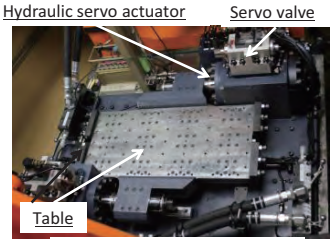


Platforms are swung up by rotating arm and centrifugal acceleration acts on the specimens on the shaking table.

Fig. 1: Dynamic Geotechnical Centrifuge



The shaking table is fixed on the platform.



Shaking table system photo

Redevelopment of DC Test Lines and Related Facilities

Background

A proposal was received for fundamental planning from the Electric Power System Council of Japan (ESCJ), and construction of DC transmission lines between Tokyo and Chubu, as well as between Hokkaido and Honshu, is underway at related electric power companies.

To estimate the electric environment of planned DC overhead transmission lines, gantry towers, DC high voltage sources and ion flow phenomena testing yard are maintained and prediction and evaluation methods of the DC electric environment are developed.

Outline

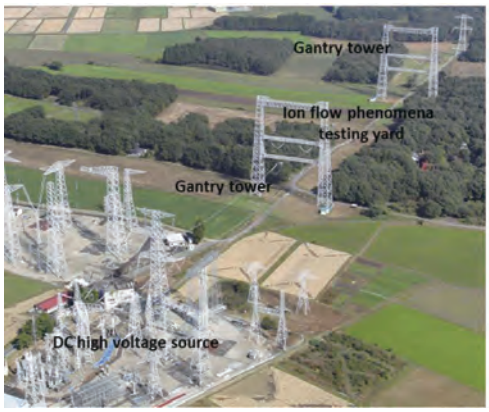
DC test lines and related facilities consist of test lines, DC high voltage sources and measuring systems. Gantry towers can set the arbitrary location of test lines due to the fact that the arms which support test lines are movable. It is possible to choose polarity of the voltage optionally as DC high voltage sources can change the form of rectifiers. At an ion flow phenomena testing yard with an area of 30 m × 80 m, it is possible to measure disposition characteristic of the ion flow phenomenon and weather conditions.

Specifications

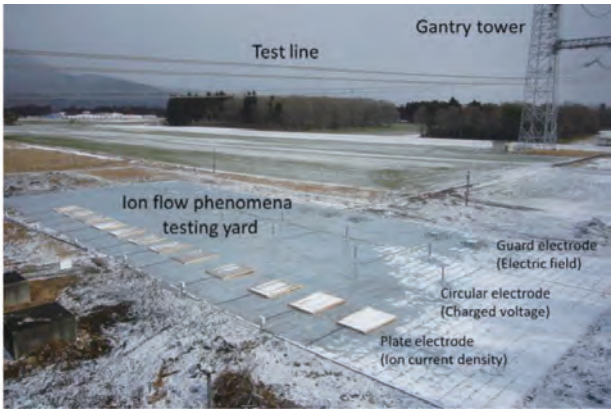
- Test line: Double circuit (Total length 750 m, Measuring span 310 m)
- DC high voltage source: 2devices (0~±800 kV)
- Measuring system

  Charged voltage (Circular electrode) : 12ch
  Electric field (Guard electrode) : 5ch
  Ion current density (Plate electrode) : 12ch
  Corona loss: 4ch
  Audible noise: 2ch
  Radio interference: 2ch
  Weather observation: Anemometer, Thermometer, Barometer, Hygrometer, Precipitation detector, Rain gauge, Pyrheliometer

[Location and date of installation]
Shiobara testing yard, March 2015



DC test lines and related facilities



Ion flow phenomena testing yard

Battery Materials Production and Evaluation Facilities

Background

The application of lithium-ion batteries has recently expanded from mobile-use to electric vehicles, residential, and leveling on grid use in line with the increased capacity and improved life performance of these batteries. When we apply lithium-ion batteries to the grid, a precise evaluation technology of battery performance is required for the proper operation period and the introduction of the next generation batteries. The determination of the degradation factors of the large format batteries is quite important in estimating the proper operation period, so that the post analysis and re-assembling technique of the large format batteries is important to judge the degradation mechanism of the battery. In addition, model cell production and its precise evaluation are also required to understand the reaction mechanism of advanced batteries with the novel materials. To accomplish the above, battery materials production and evaluation facilities were installed in Yokosuka area. Some of the existing equipment in Komae area was also relocated to the Yokosuka area.

Outline

The majority of the battery components are sensitive to high humidity so we installed a dry room with ultimate dry air conditions and directly connected glove boxes with inert Ar gas atmosphere. This system deals with the disassembly of the various small-sized batteries and 50 Wh class large format batteries. We can also analyze component chemistry and reassembly of the batteries in the glove box to understand each electrode performance of the dissembled batteries. In addition, advanced material production system, electrode synthesis equipment, and cell production system are prepared to correspond to the proper analysis of the advanced materials in the large format batteries.

Specifications

-Dry Room: 100 m^2, Dew point of the blow off gas: <-70℃ (<3 ppm H_2O)
-Vacuum Glove Box: Direct connection to Dry Room, Dew point of the blow off gas: <-100℃ (<0.01 ppm H_2O)
-Ultra dry production system: Dew point of the blow off gas: <-90℃ (<0. 1 ppm H_2O)
-Battery material synthesis equipment: Furnace temperature >1,000℃. Various gas (O_2, Ar, N_2) purge supply system are connected the furnace.

[Location and date of installation]
Yokosuka area / March, 2015

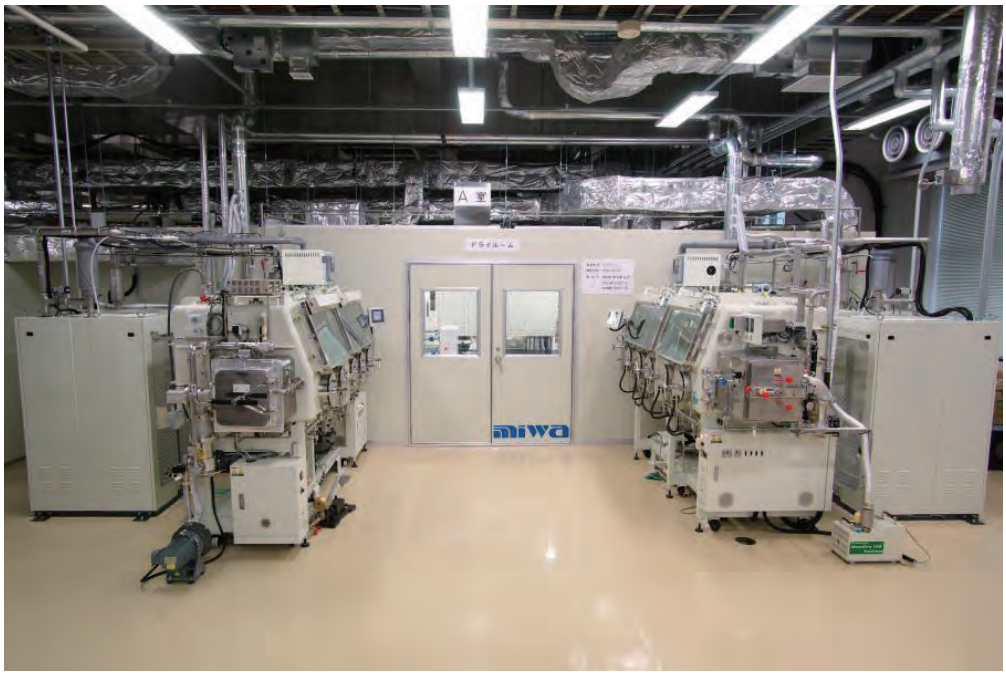


Photo 1: External view of the battery materials production and evaluation facilities

4. Activities

4. Activities

The activities of the CRIEPI in FY 2014 are outlined below.

1 Human Resources

The CRIEPI employs 796 people as of 31st March, 2015. 697 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. 401 people working at the CRIEPI have a Ph.D. Of these, 73% and 11% have an engineering and science background respectively.

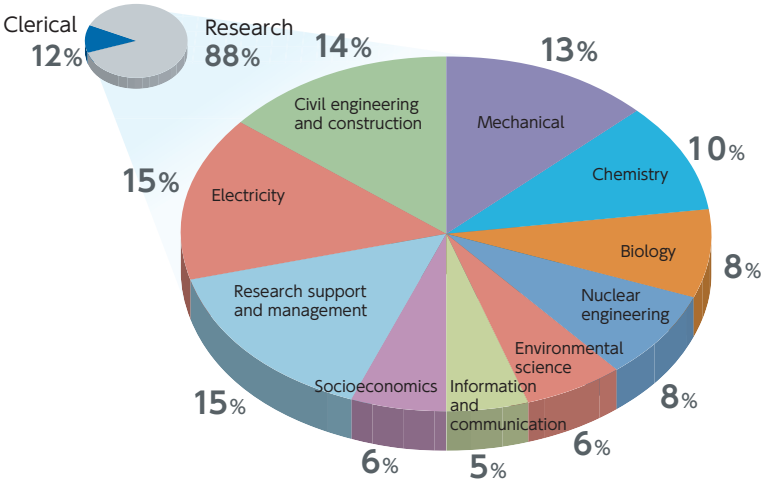


Fig. 1: Staff breakdown

2 Research Reports

A total of 453 CRIEPI research reports were produced in FY 2014. Of these, 270 were research reports and 183 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.

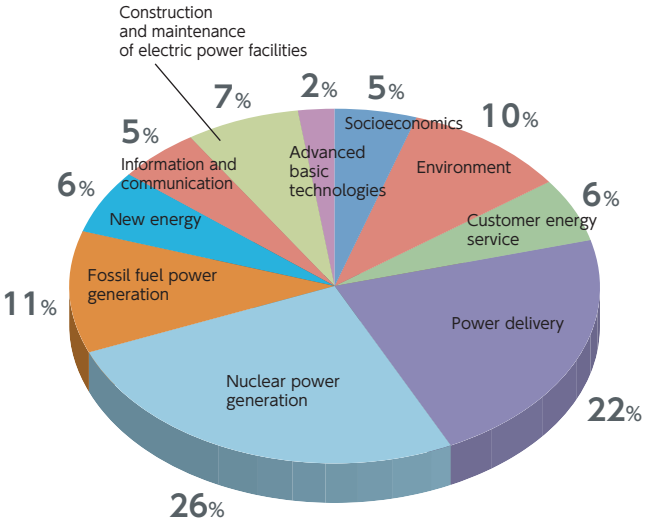


Fig. 2: Breakdown of reports by subject field

3 Presentation of Research Papers

A total of 1,412 research papers were presented in bulletins of academic societies and academic journals and at academic conferences. Of these, 350 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.

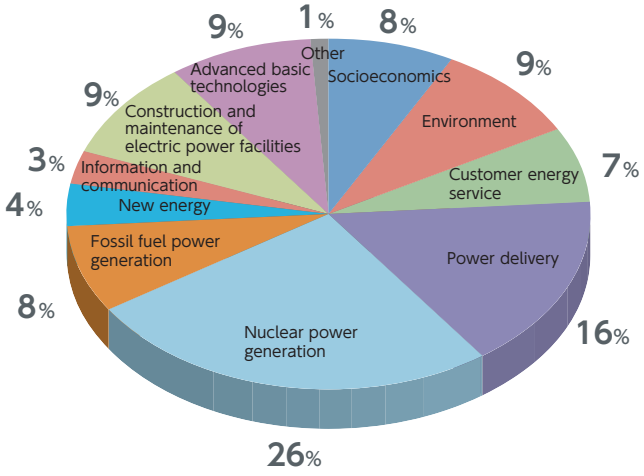


Fig. 3: Breakdown of research papers by subject field

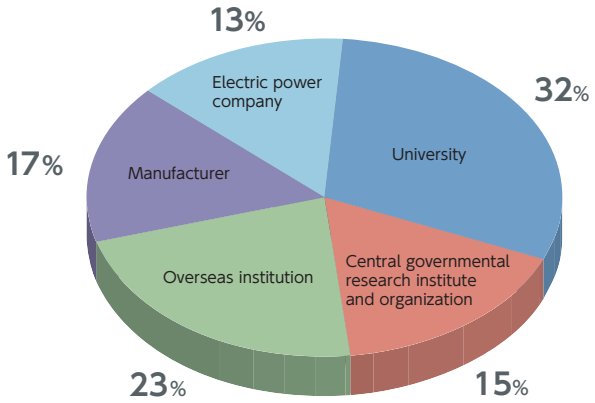


Fig. 4: Classification of research partners

4 Research Cooperation / Interchanges

4-1 Joint Research

Joint research projects were conducted 181. As shown in Fig. 4, universities and central governmental research institutes, etc. accounted for 32% and 15% of the research partners respectively.

4-2 Main International Cooperation/ Interchange Schemes

CRIEPI has been advancing joint research, information exchange and human interaction with a number of research institutes overseas. Fig. 5 shows the main overseas institutes with which CRIEPI has concluded international agreements for cooperation. Table 1(p.104) lists the main partners of CRIEPI for international cooperation / interchange.

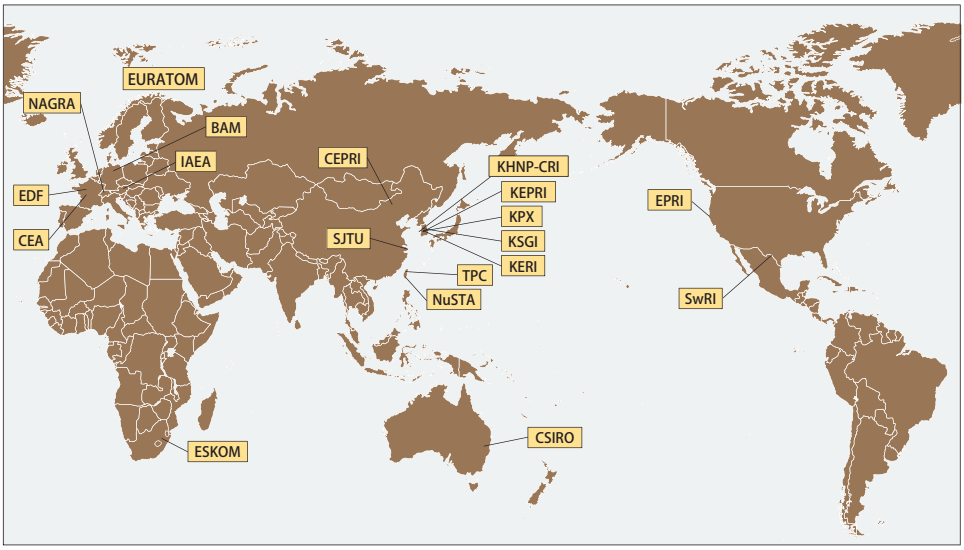


Fig. 5: Main partners for research cooperation

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

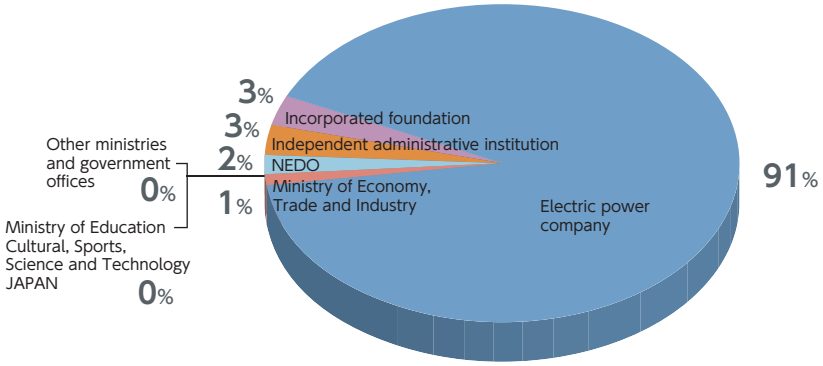


Fig. 6: The consigned research and breakdown of the consignor of the consulting

4-3 Consigned research and consulting

There were 693 cases of consigned research. A breakdown of the consignor of the consigned research is shown in Fig. 6. There were 25 cases of consulting.

4. Record of Activities The following is a summary

Table 1 Main international cooperation/interchange partners

Main Partners for Research Cooperation Agreement

Asia

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

North America

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), Austria

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)
United States Department of Energy (DOE)
United States Nuclear Regulatory Commission (NRC)
National Institute of Standards and Technology (NIST)
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 AB, Sweden
National Cooperative for the Disposal of Radioactive Waste (NAGRA), Switzerland
Comenius University in Bratislava, Slovakia
Studiecentrum voor Kernenergie - Centre d'étude de l'Energie Nucléaire (SCK・CEN)
Organization for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA)
European Technology Development Ltd. (ETD), UK
Institute for Energy Technology (IFE), Norway
European Atomic Energy Community (EAEC/EURATOM), EU
Institute for Transuranium Elements (ITU), Germany
Gesellschaft fur Nuklear-Service mbH (GNS), Germany
Friedrich Schiller University Jena, Germany
Leibniz Institute for Solid state and Materials Research (IFW), Dresden, Germany
Gesellschaft fur Anlagen – und Reaktorsicherheit mbH (GRS), Germany
Jacobs University Bremen, Germany
Polytechnic University of Turin, Italy
National Research Council, Italy
University of Twente, Netherlands
Nuclear Research and Consultancy Group (NRG), Netherlands

Other (involvement of institutes from multiple countries)

Mont Terri Consortium
Halden Reactor Project

Participation in International Organizations

International Atomic Energy Agency (IAEA), Austria
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 2014.

5 Forums, Seminars and Other Events

The following forums, seminar and open laboratory were organized in FY2014.

●Research Results Debriefing Session 2014
"For Coexistence with Limited Fuel Resources and the Environment"
May 22th, 2014, IINO Hall, Tokyo

●Open Laboratory
May 24th, 2014, Akagi Testing Center
October 4th, 2014, Abiko Area
October 18th, 2014, Yokosuka Area
October 26th, 2014, Komae Area

6 Industrial Property Rights

The patent registration and the breakdown of each field of application are shown in Fig. 7 and Fig. 8 respectively. 115 patents were registered and 84 patent applications were made in FY 2014. 52 patents or know-how were newly licensed in FY 2014.

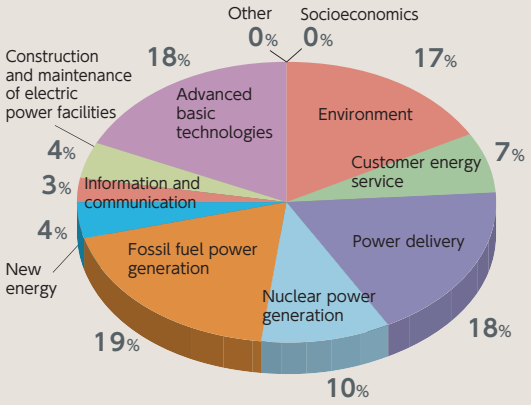


Fig. 7: The breakdown according to the field of the patent registration

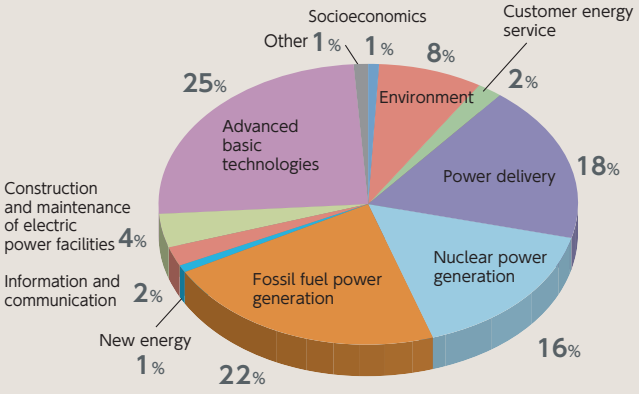


Fig. 8: The breakdown according to the field of the patent application

7 Software

The number of new software registrations and the number of new licenses awarded were 78 and 440 (1978 copies) respectively. Main software with much number of the licensing is shown in Appendix (2).

CRIEPI's home page is a free and publicly accessible service. The "CRIEPI's World Wide Information Service" (http://criepi.denken.or.jp/) provides access to the summaries of a number of non-confidential research documents, as well as publications such as "CRIEPI News".

Locations

Otemachi Area

- Head Office
- Nuclear Risk Research Center
- 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

- System Engineering Research Laboratory
- Nuclear Technology Research Laboratory
  - Radiation Safety Research Center
  - Human Factors Research Center
- Komae Operation & Service 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
- Procurement 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

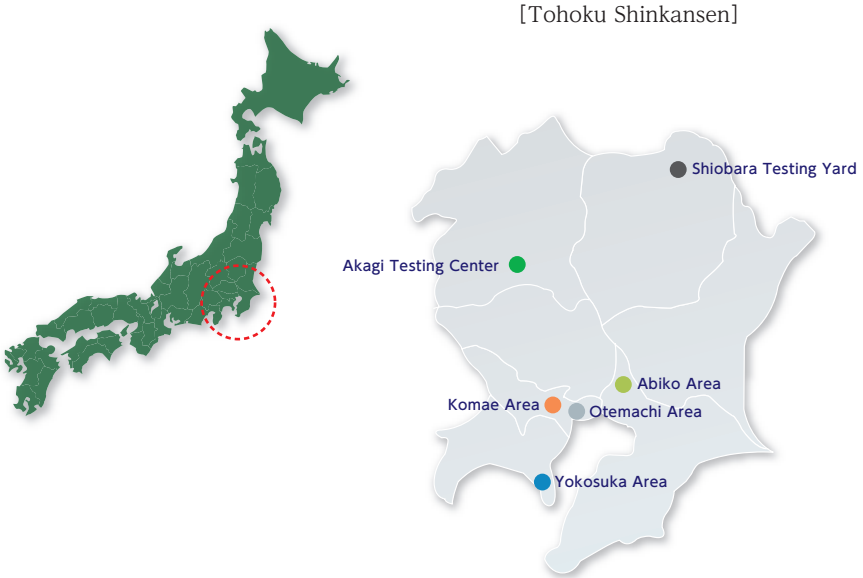
2-6-1 Nagasaka, Yokosuka-shi,
Kanagawa 240-0196
Phone: +81-46-856-2121
Approx. 35 minutes by bus from Zushi Station
[JR Yokosuka line]

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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