Central Research Institute of Electric Power Industry

Annual Research 2011 Report Fiscal Year



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Organization of the Central Research Institute of Electric Power Industry



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Annual Research 2011 Report Fiscal Year



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1. Outline of Research Activities

CRIEPI's R&D Portfolio (Pillars of research and eight research laboratories)

1. Outline of Research Activities

In FY 2011, the devastating earthquake brought drastic change to the electric power industry and Japanese society. In response to these changes, CRIEPI specified three areas as its main "pillars of research" for governing the mid-term direction of the institute's research activities, which seek to help build both a robust and flexible energy supply-demand structure in Japan. The first area is the Establishment of Optimal Risk Management, the second is the Further Improvement of Facillity Operations and Maintenance Technologies, and the third is the Development of a Supply/Demand Infrastructure for Next-Generation Electric Power. Working in line with these directive principles, CRIEPI has focused its research resources on select research projects to address the challenges of adjusting to the changes in the electric power industry and society, ensuring a stable supply of electricity, and establishing an energy supplydemand infrastructure for the future.CRIEPI utilized its expertise and the broad range of base technologies it owns to rapidly respond to some of the most urgent issues, including those related to earthquakes, tsunamis, and nuclear power plant accidents.

CRIEPI selected the "Project Subjects" as the most needed by the electric power industry and society, and for which the timely delivery of results and planning for implementation were required. The R&Ds on these subjects were conducted, drawing upon the collective strength derived from the cross-sectional collaboration of eight research laboratories.* In addition, CRIEPI efforts were also made to addressing future challenges, conducting research on key base technologies that serve as a source of solutions to problems, such as technologies that need to be maintained and passed on, those that need to be further developed, and those required for new research operations. To address these "Basic Technology Subjects," CRIEPI has utilized the distinctive features and expertise of each research laboratory to prepare and improve these technologies.

In FY 2011, CRIEPI conducted research on 38 project subjects and 36 basic technology subjects, as shown in the "Breakdown of Research Projects." It also placed a high priority on the research of the Plant Life Management Project which brought together four project subjects covering the aging of materials used in light-water reactors.

The principal research results in FY 2011 are described in Chapter 2. This chapter lists the different challenges addressed by each project subject, the basic technology subjects addressed by each specialized research laboratory, and the respective aims of each subject.

To facilitate the efficient generation of research results, we introduced new research equipment in FY 2011, including a field observation system consisting of a steel transmission tower exposed to wind and seismic forces, multicolor cell-sorting and electrical signal measurement system for ips cell analysis, and high-power testing facilities containing impulse current generators and small zeolite column test equipment. Chapter 3 provides an overview of these equipments. Chapter 4 summarizes the main track record of CRIEPI's research activities.

*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.

Further Improvement of Facility Operations & Maintenance Technologies

Project Subjects

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

Establishment of Optimal Risk Management

CRIEPI's R&D Portfolio in FY2011 (31st March, 2012)

Establishment of Optimal Risk Management

Energy Policies Analysis

- Sustainable Structures and Regulations for Electric Utilities
- Energy Technology Strategy

Improvement of Seismic Reliability

Seismic Margin Evaluation of Civil Engineering Structures in Nuclear Power Plants

Radiation Safety and Evaluation of Environmental Impact

- Assessment of Radioactive Material Diffusion in the Environment and its Remediation
- Elucidation of the Mechanisms of Low-dose Radiation Effects
- Rational Radiation Safety Technology

Backend Management in Nuclear Fuel Cycle

- Storage and Transport Technology for Spent Nuclear Fuel
- High-level Radioactive Waste Management
- Low-level Radioactive Waste Disposal

Natural Disaster Countermeasures at Power Transmission and **Distribution Facilities**

- Evaluation of Damage to Overhead Transmission Facilities Caused by Wind, Snow, and Salt
- Strategic Disaster Restoration Support Technology for Electric Power
- Distribution and Substation Equipment Lightning Protection for an ICT-oriented Society

Global Warming Projections and Impact Assessment

- Long-term Global Warming Projection and Support for Adaptation
- Severe Storm Prediction and the Impact Assessment of Electric Power Facilities under Global Warming

Project Subjects

Further Improvement of Facility Operations and Maintenance Technologies

Development of Plant Life Management Research for Nuclear Reactors

- Irradiation Embrittlement and Structural Integrity of Reactor Pressure Vessels
- Stress Corrosion Cracking in Light-water Reactors
- Wall Thinning and the Seismic Evaluation of Piping
- Deterioration Diagnosis of Instrumentation and Electrical Equipment

Operation and Maintenance Support for Electric Power Generating Facilities

- Disaster Prevention and Maintenance for Hydropower Facilities
- Integrated Remaining Life Assessment Technology for Inspection, Prediction, and Monitoring

Operation and Maintenance Support for Electric Power Transmission and **Distribution Facilities**

- Operation and Diagnosis of Aged Power Apparatuses for Substations and Underground Power Transmission Lines
- Development of Simple Method for the Cleaning of PCB-contaminated Transformers

pment of a Supply/Demand Infrastructure for Next-generation Electric Power

Next-generation Thermal Power Technologie

- Expansion of Fuel Types and the Improvement of Efficiency in IGCC
- Utilization of Low-grade Fuel Advanced Utilization Technology
- of Biomass and Waste Thermal Power Generation Systems with CO2 Capture Basic CO2 Storage Technology
- Development Considering Geological Structure in Japan

Next-generation Grid **Technologies**

- Integrated Operation and Control Techniques for Supply and Demand in
- Autonomous Demand Area Power Systems Next-generation Communications Network Systems
- Evaluation of the Feasibility of Demand Response Suitable for Japan
- Operation of Trunk Power Systems in a Coordinated Manner with Autonomous Demand Area Power Systems
- Next-generation Electric Power Equipment for Distribution and Transmission Systems

Electrification and Energy

- **Conservation Technologies**
- Design Support for Electric Kitchens High-efficiency Heat Pumps
- Low-loss Power
- Semiconductor
- Low-loss Compact Inverter Applied Equipment
- Acceleration of Electrification with Electric Vehicles and Secondary Battery Systems
- Lithium Secondary Batteries with Reliable Safety

Basic Technology Subjects

Socio-economic Research Center Utility Management and Policy Economic and Social Systems Energy Technology Policy	System Engineering Research Laboratory Electric Power Systems Customer Systems Communications Systems Mathematical Informatics	Nuclear Technology Research Laboratory • Nuclear Power Generation Technology • Advanced Nuclear Fuel Cycle • Reactor Systems Safety • Human Factors Research • Nuclear Power Technology Applications/Innovative System Assessments	Civil Engineering Research Laboratory Geosphere Science Earthquake Engineering Structural Engineering Fluid Dynamics
Environmental Science Research Laboratory Atmospheric and Marine Environment River and Coastal Environment Biological Environment Environmental Risk Assessment Biotechnology	Electric Power Engineering Research Laboratory • High-voltage and Insulation • Lightning and Electromagnetic Environment • Applied High Energy Physics • Electric Power Application • High Current Technology	Energy Engineering Research Laboratory High Efficiency Power Generation Advanced Fuel Utilization Heat Pump and Thermal Storage Energy Conversion Engineering Innovative Numerical Simulation Technology	Materials Science Research Laboratory Materials for Nuclear Energy Materials for Thermal Power Plants Batteries and Electrochemical Materials Advanced Functional Materials PD (Performance Demonstration) Certification System

2. Principal Research Results

Project Subjects—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

Establishment of Op Risk Managemer

Project Subjects

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Project Research — Establishment of Optimal Risk Management Sustainable Structures and Regulations for Electric Utilities

Background and Objective

The Great East Japan Earthquake in 2011 urged a revision of energy policy in Japan. This envisions not only the promotion of energy efficiency and the acceleration of the diffusion of renewable energy, but also the reform of the structure of the electric power industry as well as its rate system. For policy discussion on these issues to be beneficial for customers and to take into account a longterm point of view, it is highly important to provide results of analyses based on objective research.

In this project, we aim to present a framework for the sustainable structure of the electric power industry and for the rate regulation that will reach a consensus in society, based on our research on the international experience of electric restructuring.

Main results

Case Studies of Electric Unbundling in the U.S.: Impacts on the Electric Utility Industry

After categorizing electric unbundling in the U.S., we selected three different states for case studies on the process of unbundling and the impact on the industry (Y11036). The unbundling in the U.S. involves the operational unbundling of transmission activities by establishing the Independent System Operator or Regional

Transmission Organization (ISO/RTO), and in some states it also involves the divestiture of generation assets (Fig. 1). ISO/RTOs without asset ownership have been more responsible for coordinating generation and transmission, but this is becoming a cause of concern, as it might increase inefficiency in the long run.

2 International Comparison of Electricity Prices Based on their Components with Country-specific Backgrounds

We overviewed the recent trend of electricity prices in key countries and investigated the factors behind price changes, such as the energy policy and generation mix in each country (Y11013). In Germany and Denmark, which promote renewable energy, electricity prices for household customers are higher than those in Japan reflecting higher public charges (Fig. 2). We also showed that the price ratio of household and industrial customers tended to be increased in countries abolishing price regulation after liberalization, such as in the U.K.

3 Issues Regarding Electricity Rate Regulation in the U.K.: Network Tariffs and Social Tariffs

We investigated the network tariffs of the U.K., which previously focused on efficiency but has since changed to evaluate the effect on investment in the long term. We analyzed the effectiveness of this new network tariff system to ensure the long-term view of network companies (Y11012). We also investigated the experience of social energy tariffs in the U.K. (Y11017) and discussed issues regarding the obligations of energy suppliers to offer discounted tariffs to low-income customers after market liberalizations (Table 1).

4 Residential Customer Attitudes toward Smart Meters and Home Solar Power Generation Systems

A questionnaire survey for residential customers in Japan was conducted to investigate customer acceptance and preference regarding electricitysaving measures by using electricity rate structures and smart meters (Y11016), along with customer preference regarding home solar power

generation systems (Y11029). As a result, it was found that less than a half of all customers, who didn't choose time-of-use (TOU) rates, answered that they would like to consider choosing TOU rates (Fig. 3).





Issues	Details
Suppliers cannot determine the eligible customers.	 Customers eligible for social tariffs are not necessarily fuel-poor households. Suppliers cannot utilize public data such as that regarding pensions.
Social tariffs do not eradicate the root cause of fuel poverty.	 Social tariffs do not contribute to the energy efficiency of home buildings and appliances, which is the root cause of fuel poverty. Unlike energy efficiency assistance, the effect of social tariffs does not last for long. Social tariffs may discourage household energy conservation incentives.
Cost allocations are difficult.	 Cost was recovered through utility bills, which, in turn, expanded customer burden. In financial deficits, it is unrealistic to compensate the cost from the Treasury.



Want to consider choosing a new TOU rate (if a new one is provided), 35%

Fig. 1: Categorization of electricity unbundling in the U.S.

In the U.S., electricity unbundling involves the operational unbundling of transmission from generation by establishing the Independent System Operator (ISO) or Regional Transmission Organization (RTO), and in some states it involves legal or ownership separation of generation assets as well. In recent years, the roles and responsibilities of the ISO/ RTO without asset ownership have become even more important in ensuring short-term reliability as well as long-term transmission planning, but their inefficiency has been a cause of concern.

Fig. 2: Electricity prices for household and industrial customers in key countries (2010, including tax)

Electricity prices in Germany and Denmark are higher than those in Japan. This is attributed to higher public charges for household customers in these countries.

Note: The data shown consists of the average unit prices provided by the IEA. For Germany, Spain, and Korea, the prices from 2009 are shown. For France, the data obtained from Eurostat is shown. For the U.S., the data in states with higher and lower prices are depicted and connected by a dotted line.

Table 1: Issues regarding social tariffs in the U.K., 2008-2011

In the U.K., after household electricity and gas bills rapidly increased since 2004, energy suppliers offered social tariffs, in response to political pressure from the government. Judging from the current situation where energy tariffs are discounted to protect household customers, some commentators now consider the liberalization of household energy markets as unsuccessful.

Fig. 3: Residential customer preference regarding TOU rates

Only 4% of all customers, who didn't choose current time-of-use (TOU) rates, answered that they would like to consider choosing current TOU rates within one year. About 40% of customers answered that they would like to consider choosing TOU rates if new TOU rates, in which time slots could be suitable to customer life styles, would be provided, in addition to current TOU rates. It was found that customers who preferred choosing TOU rates would be willing to save peak electricity demand because of their high awareness of electricity conservation.

Note: The survey was conducted in October and November 2011. Respondents who didn't choose current TOU rates during the survey dates were asked this question. (About 80% of respondents, n=2,126)

Energy Technology Strategy

Background and Objective

In order to tackle global warming and energy security issues, it is necessary to implement an energy policy effectively under a long-term strategy pertaining to technology research and development. To do so, in addition to technology perspectives, it is important to specify the social, economic, and political factors that inhibit or promote development and diffusion based on case studies, as well as to provide policy implications. This research project aims to provide implications to contribute to building an energy technology development and dissemination strategy, by taking into account the recent situation of energy policy discussion after the 2011 Great East Japan Earthquake.

Main results

Questionnaire Study Regarding Household Energy Use in the Area Devastated by the Great East Japan Earthquake

This study analyzes household energy use in the affected areas, Iwate, Miyagi, and Fukushima, of the Great East Japan Earthquake. Regarding supply disruption and the rehabilitation of lifelines, propane gas showed the least damage among lifelines. The order of the recovery of utility services was as following: electric power, propane gas, water, city gas, and kerosene gasoline (Fig. 1). Realizing a rational restructuring agroforestry community after the earthquake, we focused on the multi-functional roles of Japanese farmland and artificial forests.

2 Ex-post Analysis of Electricity Conservation in the Summer of 2011

We conducted interviews and a questionnaire survey of households in TEPCO's service area and analyzed the conservation rates (Fig. 2), motives, persistence, and the importance of information provision regarding peak electricity conservation (Y11014). We also conducted a questionnaire survey with industrial and commercial facilities (Y12002), as well as a case study of the retail sector (Y11034). We showed that firms in the commercial sector successfully saved electricity by reducing lighting and air conditioning use, while those in the industrial sector had to take costly measures such as limiting operations (Fig. 3).

3 Domestic Policy of Energy Efficiency and Climate Change

The differences in the adoption rate of energy-efficient technologies between market segmentation as well as consumer attitudes are revealed based on a survey of residents living in houses built in 2010 (Y11015). Also, we discussed the success factors of voluntary initiatives by industry, based on case studies including measures to reduce standby power consumption by consumer electronics manufacturers.

Research trends Regarding Geoengineering

In Europe and the U.S., simulation studies of geoengineering, which suppresses global warming artificially, is increasing, and the discussion of an international framework for research and development is becoming active. By reviewing such status, research needs and challenges in Japan are discussed (Y11008).

5 Investigation of the International Aspects of Climate Policy and Energy Security

We analyze the emergence of emerging economies and the impacts on climate negotiations and conclude that it is highly difficult for countries to agree on a new legal framework applicable after 2020, while COP17 decided that they would adopt such by 2015 (Y11028). We investigate Chinese efforts to acquire technologies necessary for shale gas development and show that China is accelerating its domestic technology development and technology transfers from abroad (Fig. 4) (Y11031).





Reducing air conditioner usage time Adjusting air conditioner temperature settings Reducing lighting usage time Switching to energyefficient refrigerator Adjusting rice Cooker power Adjusting rice Cooker power Adjusting rice Cooker power Adjusting to an energyefficient TV 0% 1% 2% 3% Overall electricity, adjusted for weather conditions

Fig. 2: Main electricity conservation measures with high overall effects In the residential sector in the Kanto region

in the summer of 2011

After excluding the effects of weather conditions, the amount of electricity used in July through September 2011 decreased by 10% on average from the previous year. About 40% of the reduction in electricity use resulted from conservation of electricity used for air conditioning, with reductions in the time air conditioning was used accounting for just under 3% of the total energy savings during the studied period.

Fig. 1: Lifeline supply disruption rates from March 11, 2011 to four weeks later

The following is the order of the recovery of utility services: Electric power, propane gas, water, city gas, and kerosene gasoline.



Fig. 3: Peak demand reduction by measures implemented in the industrial and commercial sector in eastern Japan in the summer of 2011

Major contribution in the commercial sector comes from lighting and air conditioning use, while major measures taken at industrial firms were shifting hours of operation to midnight and/ or the early morning, increasing the capacity of in-house power generators, and limiting operations. The latter turned out to be costly and saw adverse effects on production activity.



Fig. 4: Chinese efforts to acquire shale gas development technologies

Currently, Chinese national oil companies and their service companies seek to build production capacity and technical capacity for shale gas development through domestic technology development and international technology transfer. Although they make multi-pronged activities to acquire technologies, they may have difficulty absorbing tacit knowledge, since it requires time to accumulate necessary experience.

Seismic Margin Evaluation of Civil Engineering Structures in Nuclear Power Plants

Background and Objective

After the nuclear accident at the Fukushima Daiichi Nuclear Power Plant following the 2011 Great East Japan Earthquake, electric power companies have been required to make a re-evaluation of the seismic safety of existing power plants (back check) and a preliminary assessment of the comprehensive assessment of safety (stress tests).

In this project, we aim to investigate the limit of strong-ground motion and the functional limit strength of structures, as well as to provide a comprehensible explanation of seismic margin.

Main results

Evaluation of the Simultaneous Rupture of Active Faults

It is important to evaluate the magnitude of an earthquake caused by multiple active faults, taking into account simultaneous effects. Some factors for the simultaneous rupture assessment of faults were found through geophysical, tectonic geomorphologic, and paleoseismological investigations, along with numerical and experimental studies from the 1891 Nobi earthquake. For example, the results suggest that a stress field will control the direction of fault rupture and that the length ratio of the cross-structure to a fault segment is associated with the possibility of the propagation of fault rupture beyond the cross-structure (N11047) (N11046) (N11049).

Attenuation Measurements of Hard Rock Ground and its Systematization for Earthquake Ground Motion Estimation

It is necessary to validate the damping factor (attenuation) of hard rock ground in the formulation of "Design Basis Earthquake Ground Motion Ss" of a nuclear power plant. The main issues of the validity of attenuation are as follows: the reason why the damping factor of near-surface rock ground is larger than generally thought; and the validation of the damping factor estimated at a site that has no vertical-array seismic observation records. The study found that the standard deviation of the heterogeneity of the near-surface rock ground obtained from borehole velocity logging relate the damping factors with each other, which are independently estimated from verticalarray seismic observations, borehole PS-logging, and laboratory measurements using ultrasonic waves. The results showed that heterogeneity of the near-surface rock affects the attenuation and that the damping factor at a point where there are no seismic observation records can be evaluated from borehole PS-logging and laboratory tests of core samples (N11063) (N17).

3 Development of a Seismic Margin Risk Diagram

A seismic margin risk diagram can represent the relationship between structural capacity based on the intensity of earthquake ground motions (i.e., peak ground acceleration) and seismic risk. This type of diagram is characterized by the fact that it can link the seismic margin of structures evaluated in a deterministic way to probabilistic seismic risk (or the annual probability of failure) (N10007). The proposed diagram can be applied to the seismic risk assessment of critical structures and components in the system analyses of nuclear power plants.



Fig. 1: Indices of the simultaneous rupture of active faults

(a) The results of the experimental and numerical studies showed that the rupture plane expected from the stress field overrode the initial discontinuity, which suggests that the stress field will control the direction of fault rupture. (b) The results from this study and other research showed that the length ratio of the cross-structure, which is another fault or a geotectonic line between fault segments, to the fault segment, is associated with the possibility of the simultaneous rupture of the fault segments.

(a)



Fig. 2: Attenuation characteristics of hard rock ground

(a) and (b) Conceptual diagrams on the relationships of damping factors estimated from seismic observations, borehole PS-logging, and laboratory tests of rock cores; (c) the seismic ground response evaluated by using the damping factor from seismic observations with a homogeneous layered model is equivalent to that evaluated by using the damping factor for the rock core with an inhomogeneous media model derived from PS-logging.

Assessment of Radioactive Material Diffusion in the Environment and its Remediation

Background and Objective

An urgent task is to clarify the current status of environmental contamination caused by the release of radioactive materials from the Fukushima Daiichi Nuclear Power Plant accident in order to assess the environmental impact and the environmental remediation necessary. The degree of this environmental contamination greatly exceeds that expected for nuclear power plant accidents in the governmental guidelines in terms of the amount of radiation and damage, and thus it cannot be dealt with by conventional assessment methods. The target of this study is to clarify the current status of the above environmental contamination using cutting-edge simulation techniques, focusing on the atmosphere, ocean, and groundwater, as well as to develop techniques for assessing the amount of radioactive materials falling from the atmosphere to the ocean and ground, which causes the spread of contamination. We also clarify the current status of soil contamination as a step toward environmental remediation as well as developing environmental monitoring techniques that can be applied to forests, which account for the majority of the contaminated region.

Main results

Clarifying the Current Status of Air Contamination and Developing Assessment Techniques

It is necessary to clarify how radioactive materials released from the Fukushima Daiichi Nuclear Power Plant into the atmosphere have been transported and dispersed in the atmosphere and deposited on the ground surface. The research team developed an atmospheric dispersion model to simulate the atmospheric concentration and deposition of radioactive materials in the Kanto and Tohoku regions (V11054). The simulated results show that the model well reproduced the temporal change in the atmospheric concentration of radioactive materials in the Kanto region (Fig. 1). The research team also discussed what part of the model should be improved for a more detailed and accurate analysis of the deposition processes of radioactive materials.

2 Clarifying the Current Status of Ocean Contamination and Developing Assessment Techniques

The advection and diffusion of radioactive materials released into the ocean from the Fukushima Daiichi Nuclear Power Plant was simulated using the regional ocean model developed by the Environmental Science Research Laboratory. The research team clarified the status of dispersion, such as the peaks in the concentration of radioactive materials in the surface layer of the ocean offshore from the Fukushima coast, and predicted the future trend of the decrease in the concentration (V11002) (Figs. 2 and 3). These simulation results were reported by TEPCO to the Nuclear and Industrial Safety Agency and then opened to the public (http://www.tepco.co.jp/cc/press/11052103-j.html). The simulation of oceanic diffusion has made it possible to estimate the amount of radioactive materials directly released into the ocean from the Fukushima Daiichi Nuclear Power Plant.

3 Decontamination of Soil and the Assessment of Long-term Environmental Impact

Conventional decontamination techniques to restore the environment and their effects should be summarized, and the current status of environmental contamination should be monitored using simple methods. The research teams simplified a method for measuring the distribution of radioactive elements in soil using a handy CsI (TI) scintillation spectrometer with a collimation technique^{*1} (V11026) and a method for estimating radioactive concentration in soil using a Geiger-Müller (GM) counter^{*2} (V11052). It was shown that these measurement methods made it possible to easily clarify the current status of environmental radio-contamination, such as the distribution of radiocesium at different depths in the soil (Fig. 5). Another research team clarified how the dose rate is affected by the amount of radiocesium on trees, which depends on the tree species and location, with the aim of establishing a radiation management system for streamlining the clarification of the status of contamination in forests and for implementing necessary decontamination work (V11027) (Fig. 4).

^{*1} The spatial dose rate refers to the radiation dose from surrounding radioactive materials per unit time in a target space and is given in microsieverts per hour (μSv/h).
*2 GM counters are devices used to measure the amount of radioactive materials in samples as a count rate by detecting the ionizing radiation in a GM tube filled with a gas used for detection.



The atmospheric dispersion model shows the spatial and temporal changes in the atmospheric concentration of radioactive materials released from the Fukushima Daiichi Nuclear Power Plant. The results shown are for March 2011 at a location (Setagaya, Tokyo) approximately 255 km from the power plant.



Fig. 4: Radiocesium contaminations of trees and the corresponding gamma-ray dose rates

Gamma-ray dose rates around trees and the cesium radioactivity of some parts of the trees were measured for various species. The results revealed that specific evergreen coniferous trees, such as Japanese cedar and Hinoki cypress, had higher radioactivity at their tree tops, and an affected dose rate around their canopies (red parts in the figure). This could be strongly associated with conditions of the fallout, the foliar morphology, and the timing of leaf expansion and defoliation.



Fig. 2: Diffusion of radioactive materials in surface layer of the ocean (simulation results)

Simulation results indicate that radioactive materials released into the ocean diffused along the coast then into the open ocean with the presence of a meso-scale eddy (April 13). The materials then spread as far as offshore of the Chiba coast (May 1). (The dots in the figure represent monitoring points.)



Fig. 3: ¹³⁷Cs concentration in the surface layer of ocean

Simulation results indicate an increased 137 Cs concentration in the surface layer of the ocean (after March 27) caused by the direct leakage from the nuclear power plant and a peak in 137 Cs concentration on April 4.



Fig. 5: Depth distribution of radioactive materials in soil

Radioactive materials diffuse to a greater depth in forested areas with large voids in the soil, whereas they remain in the surface layer of bare land. This indicates that the proportion of radioactive materials at each depth in soil depends on the soil properties.

Project Research — Establishment of Optimal Risk Management Elucidation of the Mechanisms of Low-dose Radiation Effects

Background and Objective

The current system for radiation protection has been established according to the linear nonthreshold (LNT) model, which mainly employs epidemiological data on human populations exposed to high-dose/high-dose-rate radiation and which uses a linear extrapolation down to the lowdose/low-dose-rate to estimate the possible risks. Recently, there is emerging evidence indicating that the risks associated with exposure to low-doserate radiation that is below that of 10 times higher than natural background level are lower than those estimated by the LNT model. An accurate estimation of the health risk of low-dose radiation should lead to the establishment of reasonable protection criteria supported by scientific evidence, along with the relief of public anxiety regarding radiation exposure.

This project is undertaken to illustrate that there is no increase in radiation risks at a low-dose-rate, and it aims to decipher underlying mechanisms, through human epidemiological studies in high background radiation areas (HBRAs) and experimental studies in animals and cultured cells. Thus, the scientific basis to achieve reasonableness in radiation protection criteria will be strengthened.

Main results

Epidemiological Research Study of Residents in HBRAs in China

The results from an epidemiological study of HBRA residents in Yangjiang, Guangdong Province, China were published. The group of subjects included about 32,000 persons aged 30-74 years, and the follow-up period was extended to 20 years, compared with the previous report. Mean cumulative radiation doses from natural radiation in the HBR and control-area^{*1} residents were 84.8 mGy and

21.6 mGy^{*2}, respectively. No significant increases of excess relative risk were observed for cancer mortality (Fig. 1), leukemia, or non-cancer mortality (Table 1). These results indicate the possibility that the risks associated with prolonged low-dose-rate exposure would be lower than those estimated by the LNT model, as with the results of an HBRA study in India (Fig. 1).

2 Suppression of Spontaneous Mutation by Radiation-induced Bystander Response

Radiation-induced bystander response is defined as a response of cells that are not directly targeted by radiation but that are in the vicinity of cells that have been directly exposed. Due to its nature, it has been often suggested that the number of cells in which biological effects are induced is higher than that of the irradiated cells under lowdose and/or low-dose-rate irradiation conditions where both irradiated and unirradiated cells coexisted in the same tissue. The aim of this study is, using the X-ray microbeam irradiation method, to clarify the relationship between radiationinduced bystander responses and mutagenesis, one of the requisites of carcinogenesis. Five cells within 1×10^5 cells on a dish were irradiated with a series of doses from an X-ray microbeam, and the dose response of the surviving fraction (Fig. 2A) and mutation frequency (Fig. 2B) in the bystander population was determined. Both the surviving fraction and the mutation frequency decreased at doses around 1 Gy. The similarity of these behaviors suggests that the enhancement of bystander cell killing participates in a mechanism that eliminates the cells having mutagenic DNA regions, selectively. In other words, biological effects at low-dose regions cannot be enhanced by bystander response.

*1 The area near the HBRA in which the terrestrial radiation levels are low and the lifestyle is similar to the HBRA.

*2 Unit of absorbed dose; 1 mGy = 1 mSv in this case, as the doses in this study consist of those from external exposure with terrestrial gamma rays.





	Deaths	ERR/Gy	95% CI
All cancer excl leukemia	941	-1.01	-2.53, 0.95
Leukemia	15	10.68	<0, infinity
Non-cancer diseases	4,525	0.10	-0.64, 0.94
Circulatory diseases	2,344	0.14	-0.84, 1.29

ERR: Excess Relative Risk, the value of relative risk minus one; relative risk is the ratio of mortality in the subject group versus the control group. ERR/Gy corresponds to the values of the slopes in Fig. 1, indicating an increase of relative risk per unit dose.

When both the lower limits (left figures) and upper limits (right figures) of the 95-percent confidence intervals (95% CIs) are positive or negative, it can be concluded that significant effects due to radiation exposure were detected. No significant effects on the mortalities of diseases in the table were shown.

Table 1, Fig. 1: Results of an epidemiological study of HBRA residents in China

No increase of risk with the dose was observed in comparison with the control area. This result is the same as the Indian study, and it is different from the atomic bomb survivor study, which shows the increase of cancer risks in proportion with dose. The cumulative dose of each Chinese data point in Fig. 1 was calculated as a center value of the mGy dose categories of 0-24, 25-49, 50-74, 75-99, 100-124, and 125 and up.



Fig. 2: Suppression of spontaneous mutation by X-ray-induced bystander response

(A) Effect of bystander response on the surviving fraction of Chinese hamster V79 cells as a function of the nuclear-averaged dose in the irradiated cells; the surviving fraction decreased as a result of bystander response at doses around 1 Gy, but at higher doses, the surviving fraction recovered. (B) Mutation frequency measured in the same cell populations used in Fig. 2A; the mutation frequency decreased significantly from background (0 Gy) levels at doses where the surviving fraction decreased. At higher doses, the mutation frequency did not become higher than background levels.

Rational Radiation Safety Technology

Background and Objective

Methodology on how to ensure radiation safety (i.e., no health effects due to radiation) for the public has been pointed out as a significant issue of interest since the Fukushima Daiichi nuclear accident occurred. It is required now more than ever before to explain the validity of criterion regarding radiation safety, maintaining transparency for society. In this project, a rational concept and assessment method for ensuring radiation safety are proposed to the relevant experts including newly developed criteria after the Fukushima Daiichi nuclear accident for the purpose of the improvement of accountability to society regarding radiation safety.

Main results

Verification of the Screening Level for the Decontamination Implemented after the Fukushima Daiichi Nuclear Accident

The Fukushima Daiichi nuclear accident caused the release into the environment of a substantial amount of radioactive materials, and a screening level for decontamination was implemented for the surface of the human body and for handling contaminated objects. In order to verify the screening levels for decontamination, the doses that arise from external irradiation, ingestion, inhalation, and skin contamination were assessed (Table 1).

The results show that the annual effective doses that arise from handling objects contaminated with the screening level for decontamination (i.e., 100,000 counts per minute) are lower than 1 mSv y^{-1} , which can be considered as the intervention exemption level in accordance with

the International Commission on Radiological Protection (ICRP) recommendations. Furthermore, the screening level for decontamination is also found to protect the skin from the incidence of a deterministic effect because the absorbed dose of the skin that arises from direct deposition on the surface of the human body is calculated to be lower than the threshold of the deterministic effect assuming practical exposure duration. Therefore, it can be considered that the emergency response regarding the screening level for decontamination implemented after the Fukushima Daiichi nuclear accident was the appropriate countermeasure from the viewpoint of risk management under such emergency conditions.

2 Clarification of the Low Diffusivity in the Radioactive Waste Disposal System

As for the radiation safety of a radioactive waste disposal system, it is necessary to clarify the accuracy of parameters for the performance assessment of the repository in the new guidelines of the licensing safety review. In a sub-surface disposal system, the closely packed concrete layer is expected to retard the migration of radionuclides from the repository to the biosphere. Therefore, the diffusion of radionuclides in FAC^{*1}, which is a candidate material for the construction

of a sub-surface repository, is a very important parameter. In this study, focusing on the pore structure of FAC, the diffusion of trace ions (which are hardly sorbed on cementitious materials) in hardened cement pastes was examined through diffusion experiments. As a result, the effective diffusion coefficients, D_e , of the trace ions for FAC were 1-3 orders of magnitude smaller than those for OPC^{*2} (Fig. 1) because of the continuous change in the pore structure (Fig. 2) (L11008).

^{*1} Low-heat Portland cement containing fly ash *2 Ordinary Portland cement

Ratio of radioisotopes		Case 1	Case 2	Case 3	Case 4	Case 5	
		<- I-131 rich ratio			I-131 poor ratio ->		
	(1151.05.157.05-157)		100:1:1	10:1:1	1:1:1	0.1:1:1	0.01:1:1
<i>a c</i>		I-131	410	360	150	23	2.4
Surface con	Surface contamination density [Bq cm ⁻²]	Cs-134	4.1	36	150	230	240
Ľ		Cs-137	4.1	36	150	230	240
	Manually handling	Ingestion [mSv y ⁻¹]	0.50	0.44	0.24	0.11	0.085
	objects [0.1 m ²]	Skin [mSv y-1]	1.7	13	56	83	87
Contaminated	Closely handling	External [mSv y-1]	0.041	0.11	0.35	0.51	0.53
objects	objects [1 m ²]	Inhalation [mSv y-1]	0.00076	0.00099	0.0019	0.0024	0.0025
	Remotely handling objects [10 m ²]	External [mSv y ⁻¹]	0.028	0.058	0.17	0.24	0.25
		Inhalation [mSv y-1]	0.00011	0.00015	0.00028	0.00036	0.00038
Direct deposition to skin Skin [Skin [mSv h-1]	1.0	1.0	1.1	1.1	1.1

Table 1: Calculation of doses that arise from contaminated objects and direct deposition to skin regarding the screening level for decontamination (i.e., 100,000 counts per minute)

On 19th March 2011, the Nuclear Safety Commission of Japan technically suggested the screening level for decontamination to be 100,000 cpm by assuming the use of a typical GM survey meter with a 5-cm bore. In this study, the surface contamination densities that correspond to the screening level for decontamination were calculated by assuming five cases for the ratio of radioisotopes, and the doses that arise from external exposure, internal exposure (inhalation and ingestion), and skin contamination were calculated. Even assuming that a similar deterministic effect can be observed in the case where the time integration of the absorbed dose rate of the skin from chronic irradiation (e.g., 1.0 mSv h^{-1}) reaches the lowest threshold of acute irradiation (>3 Sv), the implemented screening level for decontamination can be considered to prevent the skin from the incidence of a deterministic effect such as temporal epilation (3 Sv), erythema (5 Sv), and permanent epilation (7 Sv).



The effective diffusion coefficient (D_e) of anion (chloride, bromide, and iodide) depends on the pore structure of the hardened cement pastes. D_e in FAC is much smaller than that in OPC (Fig. 1). As shown in Fig. 2, the pore size distribution and porosity of FAC changes to become a more closely packed structure because of the pozzolanic reaction in which pozzolanic materials react with portlandite to form insoluble silicate compounds. Such changes of the micro structure of FAC lead to the low diffusivity of FAC.

2 Principal Research Results

Project Research — Establishment of Optimal Risk Management Storage and Transport Technology for Spent Nuclear Fuel

Background and Objective

The Japan Atomic Energy Commission has identified three potential nuclear fuel cycle policy options according to the share of nuclear energy supply in future. Regardless of the chosen nuclear fuel cycle option (reprocessing or direct disposal), the needs for the interim storage of spent nuclear fuel (SNF) are increasing ever-further.

In this project, to realize the early utilization of economical and large-capacity storage methodology, we are executing study programs related to concrete cask storage technologies from the perspective of cask procurement risk management and economic benefit. Moreover, to confirm the safety of the confinement components during future transport after long-term storage, we are also executing study programs for the verification of the integrity of the metal gasket under long-term dry storage conditions, and we promoted codification activities on an alternative metal cask system using ductile cast iron material.

Main results

Applicability Evaluation of Ultrasonic Tests with Imaging Analysis for Type-304L Stainless Steel Canister Lid Welding

An image reading technique using ultrasonic images collected by phase-array ultrasonic examination equipment was applied to the full-scale canister lid welding model made of type-304L stainless steel with artificial defects, and the accuracy of the proposed technique was verified and a detectable flaw size-limit was proposed (Fig. 1) (N11057). These results will be reflected on JSME (Japanese Society of Mechanical Engineers) codification activities for the ultrasonic test inspection methodology of the lid welding to verify the confinement ability of the canister.

Prevention of Chloride-induced Stress Corrosion Cracking for Type-304L Stainless Steel Canisters

Based on the chloride deposition rate tests in a salty environment condition (atmospheric sea salt concentration about 2 μ g/m³), it was found that the amount of sea salt deposition on the hot metal surface in the vertical orientation was very low (about 0.03 g/m² per year), compared with the critical value of 0.8 g/m², corresponding to SCC initiation (N11028).

In addition, in order to measure the concentration of chloride attached to the canister, the laserinduced breakdown spectroscopy (LIBS) method was applied and the possibility of the quantitative measurement of chloride concentration from 0.05 to 1.0 g/m² on the canister by LIBS was confirmed (H11020).

Moreover, we developed a salt particle collection device with low-pressure loss that does not interfere with the air flow into the concrete cask (Fig. 3). Based on these research results, a preventive design (monitoring, inspection, and countermeasures) methodology for SCC occurrence on the canister surface was realized (N11044).

Evaluation of the Long-term Containment Performance of Metal Casks

We evaluated the ageing mechanism related to the relaxation of the gasket complex under the high temperature of the aluminum gasket for metal cask confinement and proposed the Finite Element Method to predict the recovery displacement of the gasket (Fig. 4). Moreover, the containment performance of the aluminum gasket for over 60 years was numerically verified using the temperature profile that appeared during the realistic long-term storage. (These tasks have been carried out under a contract from NISA/METI.)

ASME Codification of Ductile Cast-iron Casks for the Transport and Storage of Spent Nuclear Fuel

In order to diversify the options for the metal cask, we proposed material standards (Section II) and structural standards (Section III) for a ductile castiron cask to the authoritative and international ASME (American Society of Mechanical Engineers) codes based on the research results on ductile cast-iron casks for the transport and storage of spent nuclear fuel (N11027).





1



Fig. 1: Applicability of the ultrasonic test inspection methodology for faulty weld defects

The full-scale canister lid welding models (diameter: 1.83 m, shell thickness: 12.7 mm, lid welding: depth 32 mm) made of type-304L stainless steel with artificial defects by electro-discharge machining weld defects (depth of 20-60 mm) and faulty weld defects were fabricated. An image reading technique using ultrasonic images collected by automatic phase-array ultrasonic examination equipment was applied at room temperature, and the collected images were compared with the macroscopic test results. As a result, the accuracy of the ultrasonic test with imaging analysis was verified and the detectable flaw size-limit (2 mm) was proposed. Furthermore, the defects due to the lack of fusion (red open circle) in the initial layer were detected. On the other hand, defects such as blowholes (yellow open circle) of over 2 mm could be detected.

Fig. 2: Measurement of the concentration of chlorine on stainless steel by LIBS

The chlorine spectra were measured for the samples with a chlorine concentration from 0.05 to 4.0 g/m² by using doublepulse measurement. The double-pulse measurement was designed using collinear geometry. The chlorine fluorescence intensity normalized by oxygen fluorescence intensity increased monotonously versus the chlorine concentration, from 0.05 to 1.0 g/m² in the double-pulse measurements. These results show the possibility of the quantitative measurement of the chlorine content on the canister by LIBS.

Fig. 3: Applicability of a salt particle collection device to a concrete cask

The effect of the device (L: 0.5 m, 15 plates) installed in a salty environmental condition near a seashore was evaluated. It was clarified that 40% of the salt particles in the air could be collected and that the device would not influence heat removal performance.

Fig. 4: Ageing effect on the load-deflection curve of the metal gasket after 60 years of usage

We evaluated the ageing mechanism related to the relaxation of the gasket complex under the high temperature of the aluminum gasket for metal cask confinement. The containment performance of the metal gasket after over 60 years was numerically verified using the temperature history (initial temperature: 139°) during the realistic long-term storage. The ageing analysis showed that the springback displacement of the metal gasket was kept as 0.05 mm under the realistic condition (60 years of usage). The residual linear load was larger than the lower bound for loss of leak-tightness. Thus, the long-term reliability of the metal gasket was confirmed.

High-level Radioactive Waste Management

Background and Objective

The long-term stability of underground facilities and the suppressive function of ultra-long-term radioactive nuclide migration using engineered and natural barriers are required and can be considered by looking at the geological/rock mechanical/ hydraulic properties of deep-seated rock mass in the geological disposal of HLW. In this project research, CRIEPI verifies the survey flow diagram for the PI (preliminary investigation), which was proposed by CRIEPI, and clarifies the applicability of survey technologies for the PI and the DI (detailed investigation) and the longterm behavior of near-field engineered and natural barriers.

Main results

Systematization and Verification of Survey Technology and Estimation Method for Site Selection

As a collaboration project with NUMO (Nuclear Waste Management Organization of Japan), geophysical exploration (N11038) and drilling in accordance with the survey flow diagram of the PI that was advanced by CRIEPI (N11) were conducted at CRIEPI's Yokosuka site during 2006

to 2009, and the applicability for site selection was verified (N15). In addition to this, the build process for the monitoring system in the borehole was proposed based on in-situ survey results. These results are very helpful for NUMO in planning the PI.

2 Development of Advanced Element Technology for Site Selection

The following element technologies, which were supposed to be very important for site selection, were developed and upgraded.

(1) Survey technology at the underground tunnel: Survey technology developed at the Mont Terri tunnel in Switzerland (N14) was applied to JAEA's Horonobe URL, and applicability to the Japanese site was confirmed.

(2) Groundwater dating: A new groundwater dating method using helium and carbon isotopes was developed (N10001) in order to estimate groundwater flow, and this method was applied to the Tono area. Considering the mixing process of water chemistry, groundwater flow was estimated and the validity of this method was confirmed (Fig. 1).

(3) Directional drilling technology: A horizontal borehole with a length of 950 to 1,000 m was drilled, and a hydraulic test in this borehole was carried out (Fig. 2). We then could envision the optimal realization of directional drilling from these results.

These results were reflected in the planning for the PI and NUMO technical report (2010 report). The directional drilling and groundwater dating were conducted as funded research from METI (Ministry of Economy, Trade and Industry), and these applications at the Hornobe and Tono sites were conducted as a collaboration project with the JAEA (Japan Atomic Energy Agency).

3 Development of Survey Technology and an Estimation Method for the Design of Disposal Facilities

Using a centrifuge, installing a $1/30^{\text{th}}$ model of a near-field of vitrified waste, the acceleration tests were conducted for a maximum of two months. These tests enabled the ability to estimate the

long-term behavior of the soil pressure of a bentonite buffer and the displacement of overpack for about 165 years (Fig. 3) (N11037) (N11040).



Fig. 1: Conceptual transport model of ¹⁴C and ⁴He for groundwater dating in the Tono area

A groundwater dating method for very old groundwater has been applied to a granitic area, and these results are consistent with the groundwater flow deduced from the previous investigation.







Fig. 3: Prediction experiment of long-term behavior in the near-field using the "CENTURY5000-THM" centrifuge (left: near-field model of this study, right: time-dependent change of the soil pressure of the bentonite buffer through the difference of the boundary condition)

The present results under the stress-state conditions demonstrate that the maximum soil pressures of the buffer depend on the earth pressures (Pc) and that they decrease after the maximal, which is different from the results of the previous study under the strain-state conditions (Nakamura and Tanaka, 2009).

Low-level Radioactive Waste Disposal

Background and Objective

A sub-surface disposal site constructed approx. 50–100 m underground is planned for low-level radioactive waste generated from operating and decommissioning of nuclear plants. In the safety evaluation of the sub-surface disposal facilities with pit disposal facilities, a long-term evaluation is necessary to be engineered.

In this project, we studied swelling pressure (which is caused by the infiltration of water) and the hydraulic conductivity of compacted bentonite. In addition, we studied the method for the estimation of the residence time of groundwater by using a recharge temperature for the natural barrier.

Main results

Development of a Swelling Model for a Bentonite-based Engineered Barrier during the Infiltration of Water and its Verification

Compacted bentonite-based material, which will be used as an engineered barrier in repositories for radioactive waste disposal, swells during the infiltration of underground water. Thus, events, such as the redistribution dry density and the displacement of containers of radioactive waste, will possibly occur. The accurate evaluation of these events is effective in decreasing uncertainty in the long-term safety evaluation of radioactive waste facilities. Thus, a swelling model of compacted bentonite during the infiltration of water is developed and the applicability of the model is investigated. Consequently, it is revealed that the developed model can simulate the swelling behavior of compacted bentonite during and after the infiltration of water (Fig. 1).

2 Development of an Investigation Method for the Redox Condition of Rocks Using the Self Potential (SP) Method

For the safety assessment of low-level radioactive waste disposal sites, it is necessary to evaluate the geochemical conditions of the natural barrier around such facilities. The geochemical conditions around a test cavern of the Rokkasho site was investigated using the self potential method. The results demonstrated that self potential change occurred around the oxidation front and that the oxidation condition can be detected using the self potential method (Figs. 2, 3, 4) (N11017).

B Development of an Investigation Method for Underground Geochemical Conditions

To evaluate the geochemical conditions of the natural barriers around facilities, the geochemical condition around a test cavern at the Rokkasho site was investigated. For in-situ measurements of the geochemical condition, it is necessary to consider water quality change caused by excavations, the measurement method of the oxidation reduction potential in the reduced zone, and the deterioration of the sensors (Figs. 2, 3, 5) (N11043).



(a) Swelling pressure test apparatus

(b) Test results and calculated results

Fig. 1: Swelling pressure test for compacted bentonite with heterogeneous initial density

Since the calculated results coincide with the test results, it can be said that the redistribution of the effective clay density of compacted bentonite can be simulated by the developed model quantitatively.



Fig. 2: Test cavern of the Rokkasho site

The test cavern and tunnels were excavated at depths of 50–100 m from the surface.



Fig. 4: Self potential and the zeta potential of rocks, along with the pH of groundwater

Self potential change occurred around the oxidation front. Zeta potential saw a correlation with the self potential or pH. (Zeta potential: Electric potential between a solid surface and a liquid)

Fig. 3: Geological section of the site

Investigations were conducted in a tunnel near an oxidation front (rocks were changed to brown by weathering).



Fig. 5: Measurement using a monitoring system

Groundwater from drilled holes was measured in cells. Some problems regarding the closing of tubes by precipitation and the deterioration of sensors were improved for the in-situ measurements.

Project Research – Establishment of Optimal Risk Management Evaluation of Damage to Overhead Transmission Facilities Caused by Wind, Snow, and Salt

Background and Objective

In December 2005, severe snowstorms on the coast of the Sea of Japan caused damage to overhead transmission facilities as follows: the partial collapse of transmission towers resulting from an overload of heavily accreted snow, short-circuit accidents involving transmission lines caused by galloping,* and the failure of electrical insulators, or flashover due to sea salt contained in the snow. In the winter season in 2011, there were also heavy snowfalls. These phenomena have given us a valuable precept such that the verification of the effectiveness of measures against snow-related damage and the improvement of its analysis and prediction methods are important for stable electricity supply.

In this project, the field observation of snow accretions on transmission facilities, conductor oscillation, and their related atmospheric conditions has been continued, and a consolidated database system of snow-related damage and meteorological information has also been devised, aiming to elucidate the physical process of snow-related damage and to improve its prediction methods.

Main results

Continuous Operation of Field Observations and Consolidated Data Management Systems

In order to understand the mechanisms of snowrelated damage to overhead transmission facilities, the field observation in seven sites in Japan and the operation of a data management system to store practical examples of snow-related damage and their meteorological conditions were continued. The field observation system of snow accretion consisting of simple devices using a short dummy conductor supported by fine-stranded wire ropes (N11030) was also enhanced. A simple method for judging accretion type classification as well as sets of equations for discrimination between rain, dry snow, and wet snow (N11059) were proposed through an investigation into the features of snow accretion using observed datasets. The use of the concept of classification can improve the accuracy of a snow accretion model. The field observation data of the galloping of four-bundled conductors were also analyzed in a time period when snow accretion was observed. The results show that the galloping can occur only in the limited range of wind speed, which can be reasonably explained by the increase in the static angle of attack with the wind speed (N11032).

2 Flashover Voltage Property of Snow-accreted Insulators and the Verification of the Efficiency of Measures against Snow Damage

Field observations for snow accretion properties of various types of insulators under natural conditions were continuously performed in the Niigata Kaetsu area of Japan (H11014), and 154 kV-class full-scale artificial flashover voltage tests of snow accreted insulators were also carried out (H11018). The test results showed that packed and wet snow could easily bridge the gaps between the sheds of long

rod insulators rather than cap & pin insulators and that the flashover voltages of cap & pin insulators were sufficiently higher than those of long rod insulators. It was confirmed that the substitution of cap & pin insulators for long rod insulators seemed to be reasonable as measures against the snow damage (Fig. 3).

3 Development of a Prediction Method for Sea Salt Concentrations in the Air and the Precipitation

The accretion of sea salt-rich snow on electrical insulators causes a reduction in their insulation resistance. For understanding the sea salt transportation processes and such meteorological conditions, prediction methods for sea salt concentrations in the air and the precipitation are needed. By improving Re-SPRAY (the Regional Sea Salt Physical Process Analytical Model), which could consider the phenomena in the emission, deposition, and transportation processes (Fig. 4 [a]), the sea salt concentrations in the air and the precipitation can be estimated. The coupling system of Re-SPRAY and the NuWFAS (Numerical Weather Forecasting and Analysis System) could predict the spatial and temporal profiles of sea salt concentrations under time-variable meteorological conditions. From the results of Re-SPRAY applied to a heavy snowfall event over the Sea of Japan in the winter of 2010, it was confirmed that the performance of Re-SPRAY was favorable (Fig. 4 [b]) (N11011).

*Self-excited oscillation of conductors due to wind and accreted snow or ice; if the amplitude becomes large or if the oscillation continues, the phenomenon may cause a short circuit or facility failure through fatigue.



Fig. 1: Simple device for observing snow accretion using a short dummy conductor supported by fine-stranded wire ropes (photo on the left: general view; photo on the right: close-up view of the wire clamp part)

A cylindrical snow sleeve accompanied with the conductor rotation, which is equal to that at the middle of an actual overhead wire of a few hundreds of meters, forms on the dummy conductor when the device is subjected to natural snowfall. The supporting mechanics of the dummy conductor are very simple and are easy to produce and maintain when used for field observation.



- $^{\ast}\,$ Wet snow accretion may be possible, but field data of wet accretion for this category have not been obtained .
- ** Strength of wind velocity is classified as follows: calm (< 1 m/s), weak (1 -3 m/s), medium (3 -8 m/s), and strong (> 8 m/s). Wetness of accretion is judged from wetness of precipitation particle.

Fig. 2: Schematic concept of accretion-type classification (example for the eastern Hokkaido area)

This chart uses a set of equations for the discrimination of precipitation type classification. A precipitation type is classified by temperature and relative humidity at each site, and the type of snow accretion can be identified from precipitation type and wind velocity. As the accretion coefficient and density are possible to be estimated according to the accretion type, an improved version of snow accretion model using the chart could be widely used for various climatic areas.



Fig. 3: Results of flashover voltage tests of snowaccreted insulators

The top photos show the discharge activity of snowaccreted cap & pin insulators during voltage tests. A number of air gaps formed in the snow as a result of melting. Thereafter, a long arc grew along the surface and finally developed into a complete flashover.

Snow conductivity (µS/cm)

The bottom shows the relation between snow conductivity and flashover voltage. It can be seem that cap & pin insulators show sufficient higher flashover voltage than long rod insulators.



Fig. 4: Conceptual diagram of Re-SPRAY and the numerical result

(a) Conceptual diagram of Re-SPRAY; (b) Comparison of the predicted sodium concentrations in the air and the precipitation with the measured ones; the characteristic behavior of the sodium concentration in the air and the precipitation observed on January 13 can be predicted by Re-SPRAY.

Strategic Disaster Restoration Support Technology for Electric Power Distribution and Substation Equipment

Background and Objective

In order to effectively support the restoration activities for disaster-damaged electric power distribution and substation equipment, their risk assessment and management technologies against disasters, which shall take into consideration the reliability and accuracy of obtained disaster information during the emergency restoration period, the disaster force (hazards), and the diversity of the region and equipment, are necessary. The objective of this project is to develop a disaster restoration support system for their equipment against mainly earthquakes and typhoons, which includes earthquake force and typhoon wind-force evaluation systems, equipment damage assessment systems, and emergency restoration process simulators, in order to put it to practical use in an actual target electric power supply area.

Main results

Application and Accuracy Improvement of Damage Estimation Systems

The functions of the earthquake damage estimation system (RAMPEr) and the typhoon damage estimation system (RAMPT) have been improved based on the actual operation results of Typhoon No. 12 of 2011 and the 2011 Great East Japan Earthquake.

As for RAMPEr, a new function was developed associated with correcting the seismic ground motion strength distribution evaluated by earthquake point source information (magnitude and hypocenter position, etc.), by using observed seismic intensity information consisting of information obtained from the Japan Meteorological Agency, etc., for the early stages just after earthquake occurrence. As a result, the estimation accuracy of seismic intensity distribution has improved (Fig. 1).

On the other hand, as for RAMPT, it was confirmed that an effective rainfall*, which is proposed as a typhoon damage index, is highly correlated with actual typhoon damage of electric power distribution equipment (Fig. 2). As a future subject, an improved damage estimation model with effective rainfall as one of the input parameters will be proposed to improve the evaluation accuracy level.

A part of the present study was executed as funded research from Tohoku Electric Power Co., Inc., Chugoku Electric Power Co., Inc., and Chubu Electric Power Co., Inc.

2 Verification Analysis of Earthquake Damage with an Earthquake Resistance Evaluation Tool (ELECTREE) for Substation Equipment

The strong ground motion caused by the 2011 Great East Japan Earthquake as sustained by a substation with seismic damaged equipment was estimated by ELECTREE—a developed earthquake resistance evaluation tool for substation equipment. The target substation has no seismic ground motion record. As a result, it was clarified that the seismic damage equipment has a high possibility of meeting the seismic force at its natural frequency more than a designed seismic force regulated by JEAG5003 (Fig. 3).

3 Proposal for the Deterioration Trend Analysis of Electric Power Distribution Equipment

The damage degree of electric power distribution equipment as caused by natural disasters such as earthquakes and typhoons is highly affected by a deterioration condition. Therefore, in order to improve the damage estimation accuracy against natural disasters, methods need to be proposed for analyzing deterioration trends and for estimating the remaining life of equipment. The proposed model focuses on pole transformers and utilizes an equipment management database for the above analysis and estimation. In numerical examples, a database associated with about 1.1 million pole transformers managed by the Chubu Electric Power Co., Inc. was created, and the causation of the age of the replaced pole transformer and surrounding environmental conditions, including weather conditions, was quantified. As a result, a remaining life estimation model for pole transformer is proposed. It is confirmed that the proposed model enables us to estimate the remaining life of a pole transformer based on equipment age and sea salt concentration. A part of the present study was executed as a funded research from Chubu Electric Power Co., Inc.



Fig. 1: Improvement of the evaluation accuracy of seismic intensity distribution (SIJMA)

In the 2011 Great East Japan Earthquake, as the JMA magnitude that was announced immediately after the earthquake occurrence was small, RAMPEr underestimated the SIJMA. On the other hand, the improved system enables us to correct such underestimated SIJMA based on observed seismic intensity information.



Fig. 2: Estimation of pole damage based on the effective rainfall

The time that the pole damage occurred is consistent with the time that the effective rainfall, for which the half life* is 72 hours, becomes the maximum. This result suggests that the effective rainfall has high correlation with pole damage.

*Half life: The period in which the quantity of remaining rainfall on the ground or underground becomes half of the total cumulative rainfall within a target period (1.5 hours or 72 hours is usually assumed as a target period)



Fig. 3: Comparison of the acceleration response spectrum estimated by the developed ELECTREE earthquake resistance evaluation tool and seismic design criterion of JEAG 5003

ELECTREE estimated a strong ground motion on the surface of the target substation with damaged equipment due to the 2011 Great East Japan Earthquake. As a result, it is clarified that the level of the estimated acceleration response spectrum is higher than that of the seismic design force regulated by JEAG5003.



Fig. 4: Comparison of the actual number and estimated number of renewal pole transformers

The actual number and the estimated number of renewal pole transformer are compared in Fig. 4. The total number of renewal pole transformers during the period between March 2010 and March 2011 is defined as the actual number. On the other hand, the estimated number is evaluated by the proposed model combined with the age of each pole transformer as of March 2010. The correlation coefficient between the actual and estimated number becomes 0.98. This result suggests that estimation accuracy using the proposed model is high.

Lightning Protection for an ICT-oriented Society

Background and Objective

Recently, highly sophisticated societal systems have been constructed using information and communication technologies (ICTs). These systems, however, are vulnerable to external disturbances such as lightning. Once social infrastructures such as information networks and power supply systems stop, extraordinary confusion may occur in society. In this project, we will further develop the lightning protection methods constructed so far and will establish novel lightning protection technologies to construct robust power supply systems in a society using information and communication technologies, taking the concept of lightning risk management into consideration.

Main results

Advancement of a Lightning Risk Assessment Program

New functions have been added to the lightning risk assessment program, which was developed last year for the evaluation of the lightning risk of transmission lines and the risk of instantaneous voltage dips caused by lightning. The added functions are the evaluation of the lightning risk of distribution lines and wind turbine systems (Fig. 1). In the program, relative lightning risk can be evaluated from lightning occurrence and the density of the facilities (H11008).

2 Overvoltage Characteristics Generated on Low-voltage Control Circuits and the Development of a Novel High-accuracy Analysis Scheme

To study the characteristics of surge voltages in a low-voltage control circuit, we set up a test system composed of two grounding grids, a GIS model composed of instrumental transformers (VT and CT), a digital-type protection relay equipment, and a control cable. Using this test system, we generated a very fast transient inside the GIS model, simulating the switching overvoltage, and measured the surge voltages arising in the low-voltage control. From these results, in this very-fast-transient case, we have clarified that the main cause of surge voltages is the surge transition from the primary circuit to the secondary circuit at the instrumental transformers of the VT and CT (H11015).

va To predict surge voltages in the low-voltage control (H

circuit spreading over large systems such as power plants and substations, we have developed a new surge simulation program by coupling the numerical electromagnetic analysis (the FDTD method) with the circuit analysis, which can utilize each advantage of the two analysis methods (Table 1). As a first step in applying the developed program to the surge analysis of a complicated configuration such as a low-voltage control circuit composed of a grounding grid, an instrumental transformer, protection-relay equipment, and a control cable, we calculate the induced voltages on an aerial wire over a grounding grid. The calculated results agree well with the measured results within a difference of 12%, and the validity of the developed program is confirmed (Fig. 2) (H11023).

Evaluation of Immunity Tests for ICT Equipment Installed at Power Stations

Immunity tests against four types of conductive noises: (1) electric fast transient/bursts (EFT/Bs), (2) rectangular impulses, (3) damped oscillatory waves, and (4) surges, are conducted for ICT equipment installed at power stations, among which equipment IP (Internet Protocol) devices were chosen. These noises are adopted in the current immunity standards. The observation showed that the interference to the IP transmission by the EFT/B noise was remarkable (Fig. 3). It was also shown that the rate of packet losses well correlated with the ratio of the duration of the noise to the period (H11022).





Fig. 1: An image map of the lightning risk of distribution systems

In the developed program, the lightning risk is evaluated from lightning occurrence and the density of power distribution facilities. Please note that the effects of various lightning protection is not considered in this case, and the lightning risk in a metropolitan area where the density of power distribution facilities is substantial, becomes relatively high. If the lightning protection methods are taken into consideration, the risk distribution would be different.

Table 1: Comparison between the conventional FDTD method, circuit analysis, and the FDTD method coupled with circuit analysis

Item	FDTD method	Circuit analysis	Coupled calculation	
Cables such as low-voltage control cables Equipment such as instrumental transformers	Considering realistic calculation time and memory capacity, modeling is impossible.	Modeling is possible, but it is impossible to consider an induction effect from other causes, such as grounding grids.	It is possible to take into account both the surge phenomena of control cables, instrumental transformers, and other equipment and the induction effect on control	
Grounding structures such as grounding grids	High-accuracy calculation is possible for grounding grids only.	High-accuracy calculation is impossible.	cables from large-scale grounding grids.	



(a) Calculation arrangement

(b) Calculated results

Fig. 2: Accuracy of the surge simulation program based on the FDTD method coupled with the circuit analysis



Fig. 3: EFT/B noise test waveform and examples of the evaluation of effects based on the data signal transmission rate

2 Principal Research Results

Project Research — Establishment of Optimal Risk Management Long-term Global Warming Projection and Support for Adaptation

Background and Objective

Since the IPCC Fourth Assessment Report in 2007, concerns about global warming have been growing. However, many uncertainties remain regarding future projections of climate change, thus the reliability of future climate information needs to be improved for planning for mitigation and adaptation measures against global warming.

quantification of the uncertainties. In addition, various future emission pathways are explored based upon firm scientific knowledge about climate change, reflecting the actual situation and the future prospects of energy supply. Furthermore, the impacts of global warming on power supply systems are being investigated based on regionalscale climate change information downscaled from global-scale projections.

In this project, we address the improvement of climate model projection, i.e., a reduction and

Main results

Improvement of a Climate Change Prediction Tool Used to Propose Rational Climate Stabilization Measures

Based on a wide range of literature regarding climate sensitivity, which is an index that relates atmospheric CO₂ concentrations to a degree of warming, associated scientific knowledge and an approach to global warming mitigation measures considering uncertainties about climate sensitivity have been summarized (V11019). Among such knowledge, the quantification of uncertainties has been implemented in our climate change prediction tool (SEEPLUS) as a function for comparing multiple probability distributions of climate sensitivity (Fig. 1). In addition, useful functions for studies on longterm climate stabilization and adaptation to climate change have been incorporated into SEEPLUS, such as referring to new emissions scenarios, facilitating comparisons with different climate models, additional outputs for practical indexes including the intensity of tropical cyclones, and so on.

2 Proposal for a New CO₂ Emission Pathway for Long-term Climate Stabilization

We have proposed, in collaboration with the Japan Agency for Marine-Earth Science and Technology, a new concept for global warming mitigation in order to avoid long-term risks from climate change despite allowing increased CO₂ emissions in the next few decades. A future emission pathway, as one demonstrative example based on this concept, has been designed using SEEPLUS (Fig. 2, left). An earth system model, which simulates the earth's climate and carbon cycle in detail, has been used for the global warming projection experiment along the emission pathway of our proposal. The model projection shows a declining trend in atmospheric CO₂ concentration after the latter half of the 21st century, accompanied with the gradual recovery of climate such as global mean temperature and sea ice extent (Fig. 2, right) (V11057).

3 Development of a Method to Estimate the Probability of Heavy Precipitation over River Basins

A method to estimate the probability density function (PDF) of daily precipitation over catchment areas of hydraulic dams has been developed. It computes PDFs from the outputs of climate models of coarse spatial resolution (typically 100 km). The PDFs of daily precipitation for the past 21 years have been estimated for over 20 dam basins (catchment areas are from 20 to 2,300 km²) in the Kyushu region of Japan, where extreme rainfall events occur frequently. The results show that the present method is superior to the conventional multiple regression method in terms of the capability of representing infrequent, heavy precipitation events. It is applicable to a wide range of basin areas, and also to the month of September, in which the PDF is strongly affected by typhoons. The proposed method is useful to evaluate the impact of future changes in heavy rainfall due to global warming on hydraulic power plants (Fig. 3) (V11058).


2 Principal Research Results



Fig. 1: Example of the probability distributions of climate sensitivity

Climate sensitivity is defined as global equilibrium surface warming due to a doubling of CO₂ concentration. The value of climate sensitivity is estimated to be about 3° C, but it involves considerable uncertainty that can be represented by a probability distribution. CMIP3 denotes the multiple climate models used in the IPCC Fourth Assessment Report in 2007. Fitting (1) is a log-normal distribution matching the CMIP3 models, and fitting (2) is one of the probability distributions devised for parameter uncertainties in a specific climate model.





The left figure shows the CO_2 emission pathways used in climate change projections. In our proposed pathway, CO_2 emissions are reduced to zero in the middle of the 22^{nd} century. Thus, the atmospheric CO_2 concentration can be eventually stabilized at a lower level. The reference is one of the emission pathways for the IPCC Fifth Assessment Report. The right figure shows the surface air temperature anomaly projected by an earth system model, along with observations. In the case of the proposed pathway, the surface air temperature gradually recovers in the long term, as a consequence of declining atmospheric CO_2 concentration after the latter half of the 21^{st} century due to CO_2 removal by terrestrial and ocean sinks.



Fig. 3: Estimated climatological PDF of daily precipitation

The graphs, in order from left to right, show the estimation results for basins A (491 km^2), B (34 km^2) and C ($1,440 \text{ km}^2$) in the same river system. The solid and dashed lines are the results using the present method and the multiple regression method, respectively, and the histogram represents the frequency of observed precipitations. The present method gives appropriate PDF estimates even in the positive tail, where the multiple regression analysis always underestimates PDFs, demonstrating the superiority of the present method in terms of the probability estimation of infrequent and heavy precipitation.

Project Research — Establishment of Optimal Risk Management

Severe Storm Prediction and the Impact Assessment of Electric Power Facilities under Global Warming

Background and Objective

The influence of global warming might be gradually actualized in 20 to 30 years in the future, and there is a possibility that this will affect power industries in Japan. The first purpose of this study is to improve the accuracy of the numerical weather prediction model for assisting the maintenance and operation of electric power facilities, such as delivery equipment and water power dams. The second purpose is to develop and improve the regional climate model in order to predict climate change in the Japanese region, and to make an impact assessment of electric power equipment under global warming.

Main results

Development of a Regional Climate Model to Predict Climate Change over the Japanese region

The numerical weather forecasting and analysis system (NuWFAS) developed by CRIEPI has been improved for application to regional climate prediction with a horizontal resolution of 5 km. The main improvements involve the setting and calculation methods of sea ice, sea surface temperature, soil temperature, soil moisture, snow depth, and lake surface temperature (Fig. 1) (N11009).

Using the improved model, we conducted 52 yearlong weather reproduction from 1957 to 2008 and produced a meteorological dataset over the Japanese region with the horizontal resolution of 5 km and the temporal resolution of 1 hour. Extreme value analysis is applied to the wind speeds dataset, and we can evaluate 10 minutes of mean wind speed with a 50–300-year return period (Fig. 2). The estimated wind speed map for the entire Japanese region with a resolution of 5 km will be useful for the wind-resistant design of electric power delivery equipment and for the estimation of past cumulative fatigue damage. The regional climate model developed in this study is applicable to climate simulation over the Japanese region with a specific climate change scenario.

2 Development of a Climate Model to Predict Typhoon Activity under Global Warming

To simulate and evaluate typhoon activity in the future climate, a regional model was configured as a tropical channel model, which has a north and south boundary at the latitude of 60N and 60S, with a cyclic boundary in the east-west direction. This model configuration is applied to the period of 2003–2005,

and the simulated results are compared with the observation of typhoons. The position of typhoon genesis and the tracks of typhoon movements are simulated very well, although the annual number of typhoons reproduced by the model is overestimated compared with the observation (Fig. 3).

3 Improvement of Meteorological and Ocean Models

Field measurements are carried out in order to estimate the momentum transfer from the airflow into the ocean, which is very important for the development of ocean waves and cyclones. Momentum fluxes estimated from the measured data are compared with those predicted by several bulk flux formulae in previous studies. The results show that the scaling with a saturation ratio of wind waves is preferred over other scalings (Fig. 4) (N11055). By using this formula, it is expected that the accuracy of ocean wave and sea wind speed forecasts by ocean and meteorological models will be improved.

Improvement of Short-range Precipitation Forecasts with Weather Radar

We developed a data processing system for X-band dual-polarized weather radar and improved the performance of the radar rainfall estimation method, especially in the case of heavy rainfall. We also developed a data assimilation method that brings the estimated radar rainfall into the numerical weather forecasting model. It is confirmed such that the developed method improves the short-range precipitation forecast.



135°E 140°E

Fig. 1: Comparison between the observation and estimation of lake surface temperature

The lake surface temperature model developed in this study (blue line) shows good agreements with the observation (\bigcirc), compared to the previous method (red line), which uses the sea surface temperature near the lake or at the same latitude. The lake model improves the air temperature information over the lake and near the lake.

Fig. 2: Extreme values of mean wind speeds based on the 52 year-long dataset

Using the 10-minutes mean wind speed dataset of a 52 year-long simulation with the temporal resolution of one hour, an extreme value statistical analysis is applied. The data samples at a grid point (• in Fig. [a]) are linear in the Gumbel probability paper, which shows that we can estimate the longer return period of wind speed properly. Fig. (b) represents a 50-year return period of wind speeds.





(a) Example of typhoon genesis in the model



(b) Typhoon tracks simulated for 2004



The tropical channel model is free to generate its own weather, climate, and typhoons. Fig. (a), which is a relative vortex (1/s), represents an example of simulated typhoons in a model. Fig. (b) is typhoon track simulated for 2004. By using sea surface temperature under climate change, the model can predict typhoon activity in the future climate.





(a) Momentum flux comparison

Fig. 4: Observation of air-sea momentum transfer

Field measurements (Fig. [b]) of the air/sea temperature, wind speed, ocean waves are carried out to evaluate the momentum flux transfer between the atmosphere and the ocean.

The observed flux agrees well with the bulk flux formula with a saturation ratio of wind waves.

2 Principal Research Results

Project Research — Further Improvement of Facility Operations and Maintenance Technologies Irradiation Embrittlement and Structural Integrity of Reactor Pressure Vessels

Background and Objective

The metallic materials of nuclear reactor components are used under extreme conditions, such as neutron irradiation and high temperature, resulting in mechanical properties changes such as embrittlement. To ensure the structural integrity of components during operation, the effects of neutron irradiation on reactor pressure vessels (RPVs) and core internals steels, along with the thermal ageing of duplex stainless steel used in primary pipings and pumps, need to be characterized. In this project, efforts have been devoted to: improve the accuracy of RPV embrittlement prediction at high fluences, develop a new method to monitor the amount of embrittlement, understand the detailed mechanism of the thermal ageing embrittlement of duplex stainless steels, and characterize the microstructural changes in neutronirradiated stainless steels.

Main results

Effect of Irradiation Temperature on the Embrittlement of RPV Steels

The effect of irradiation temperature on the embrittlement of RPV steels was studied by comparing the amount of embrittlement and microstructural changes in high- and low-copper (Cu)-content materials irradiated at different temperatures. The number density and size of the solute atom clusters are higher and smaller, respectively, at a lower irradiation temperature, as shown in Fig. 1, and this trend is more evident in high-Cu material. However, the increase in yield stress, which is proportional to the amount of embrittlement, is proportional to the square root of the volume fraction of the solute atom clusters irrespective of the difference in cluster morphology (Fig. 2) (Q11019).

2 Effect of Solute Atoms on the Cu-enriched Cluster Formation and Hardening of RPV Steels

The effects of solute atoms such as nickel (Ni), manganese (Mn), and silicon (Si) on the solute atom cluster formation were investigated through comparisons between the hardness and microstructural changes in thermally aged RPV model alloys containing these elements and

Cu. Ni addition results in a decrease in peak hardness, but the time necessary to reach peak hardness does not change. On the other hand, Mn addition shortens the time necessary to reach peak hardness (Fig. 3) (Q11026).

8 Round-robin Test of the Fracture Toughness Master Curve Method using Miniature CT Specimens

Toward the establishment of the fracture toughness Master Curve method utilizing miniature compact tension specimens that can be machined from a broken half of a Charpy specimen, a round-robin test was organized and conducted by CRIEPI with the participation of several domestic research organizations. It was found that valid reference temperatures, T_o^* , were determined by all the participants for a given test condition.

Effect of Temperature on the Thermal Ageing Mechanism of Duplex Stainless Steel

Thermal ageing tests of duplex stainless steel were conducted at temperatures from 350 to 450°C with a maximum of 8,000 hours of ageing time, and the microstructural changes were studied in the materials. It was identified that the number density of G-phase precipitates is higher at lower

temperatures, the size of G-phase precipitates as well as the representative distance between chromium-enriched phases becomes larger with ageing time, and the growth rates of G-phase precipitation and phase decomposition are faster at higher temperatures (Fig. 4).

*To: An index that corresponds to the temperature where the Master Curve mean fracture toughness, KJc, becomes 100 MPa√m.



Fig. 1: Effect of irradiation temperature on the solute atom cluster formation in Cu-containing (0.2 wt% Cu) material



Fig. 2: Relationship between the microstructure (volume fraction) and the mechanical property (yield stress)



Fig. 3: Effect of solute elements on the hardening of thermally aged RPV model alloys



Fig. 4: Effect of ageing temperature on the microstructural changes in duplex stainless steel

2 Principal Research Results

Project Research — Further Improvement of Facility Operations and Maintenance Technologies

Stress Corrosion Cracking in Light-water Reactors

Background and Objective

Stress corrosion cracking (SCC) is one of the degradation events that occur on structural materials in light-water reactors. Countermeasures against SCC are residual stress improvement, water chemistry improvement, the application of alternative material, and so on. In addition, methods of repair, replacement and crack growth evaluation, based on the fitness-for-service code of the Japan Society of Mechanical Engineers, are established. Although such countermeasures are well prepared, the continuous activities regarding the clarification of SCC properties, the development of countermeasures, and the improvement of codes/ standards are necessary.

One of our research objectives is to clarify the SCC initiation mechanism and condition in order to develop a crack initiation model. The other objective is to clarify the SCC growth rate and growth conditions in order to introduce such clarifications into the current fitness-for-service code.

Main results

Clarifying the SCC Behavior of Low-alloy Steel

The welded parts of the reactor pressure vessel (RPV) penetration and the attachment of core internals, consisting of nickel-based metal, are susceptible to SCC. The possibility that SCC initiated in Ni weld metal reaches the RPV (low-alloy steel) is not fully excluded. Clarifying the SCC behavior regarding low-alloy steel is thus necessary. SCC growth tests were therefore conducted to investigate SCC behavior in this study. The SCC growth rate showed greater

value at the earlier stage of the tests. Then, the SCC growth rate decreased with time (Fig. 1) (Q11023). The SCC growth rates obtained at constant K conditions were about 1/1,000th of those obtained during increasing K conditions (Fig. 2) (Q11023). This suggests that the use of growth rates corresponding to K distributions (K rates) is necessary to establish the precise evaluation of the actual components.

2 Clarifying the SCC Initiation Behavior of Low-carbon Stainless Steel

Several BWR plants have experienced stress corrosion cracking on the hardened surface of low-carbon stainless steel in a primary coolant environment. The hardened layer is induced with surface machining. The machining also causes tensile residual stress and plastic strain. It is thus possible that plastic strain distribution and stress distribution affect SCC initiation behavior. Our study using original specimens with cyclic plastic strain distribution introduced by face milling showed that SCC was preferentially initiated in areas with a large plastic strain gradient (Q10024). In addition, stress measurement using X-ray diffraction clarified that stress distribution on the specimen was negatively correlated with hardness corresponding to plastic strain distribution (Fig. 3). As a result of these studies, it was suggested that SCC tended to be initiated in areas with a stress and hardness gradient (Fig. 4) (Q11008).



Fig. 1: Relationship between the SCC growth rate and time duration

The SCC growth rate decreased with time duration. The average SCC growth rate for one year is estimated to be about 1×10^{-11} m/s. (*The estimated value for one year is a weighted average of the growth rates by 100 h and after 100 h.)



Fig. 2: Results of SCC growth tests

The SCC growth rates obtained at a constant K condition were about $1/1,000^{\text{th}}$ of those obtained during increasing K conditions.



Fig. 3: Strain and stress distribution on the specimen surface

The contrast indicates the distribution of plastic strain, with the dark area having a high degree of plastic strain. The high plastic strain area has high hardness and a low degree of longitudinal stress.



Fig. 4: SCC initiation area on the specimen surface

The hardness value indicates the amount of plastic strain in this figure. SCC cracks were preferentially observed in the areas that have steep plastic strain gradients and stress gradients as shown in Fig. 3. Project Research — Further Improvement of Facility Operations and Maintenance Technologies

Wall Thinning and the Seismic Evaluation of Piping

Background and Objective

Flow-accelerated corrosion (FAC) and liquid droplet impingement erosion (LDI) are pipe wall-thinning phenomena that require consideration regarding management of the safety and maintenance of nuclear power plants with long-term operation. Pipe wall thinning management is based on residual lifetime evaluated by pipe wall thickness measurement conducted at about a 100 to 1,000 locations per outage. In this project, to improve management by focusing on measurement location with priority, detailed local thinning profile predictions and a simplified evaluation method for a maximum thinning rate by FAC/LDI is developed. For the seismic evaluation for piping with wall thinning, while currently, conservative evaluation is required by assuming complete thinning, appropriate seismic strength for local thinning piping is investigated, which may lead to the rationalization of seismic criterion for piping with wall thinning.

Main results

Dissolved Oxygen Concentration for FAC Suppression

The FAC rate in the simulated BWR primary water at 140°C dramatically decreases when the dissolved oxygen concentration is higher than 40 to 60 ppb. The dissolved oxygen concentration is lowered to 10 ppb in the alkaline condition such

as in the simulated PWR secondary water. These results indicate that the wall thinning in the PWR secondary system will be mitigated by a small amount of oxygen injection (Fig. 1) (Q11025).

2 Development of an Evaluation Method for Flashing Erosion

LDI in a hot-water piping system due to flashing phenomena (flashing erosion) is sometimes observed. The flashing flow is defined as the flow with a sudden phase change, and it is usually difficult to simulate the flow structure of the flashing flow. Therefore, based on a steam flow CFD (Computational Fluid Dynamics) code previously developed, a pre-conditioning method was adopted to achieve the stable calculation of the water region, and a new CFD code for watersteam flow was developed. Several benchmark tests were conducted, and those results show that this new code can reproduce the flashing phenomena and is applicable to the evaluation of the flashing erosion (Fig. 2) (L11016).

Verification of the FAC/LDI Model and the Development of FALSET Prediction Software

Utilizing the maximum local thinning rate measurement data of FAC/LDI in actual power plants, the calculated values with the developed prediction method were compared. From the comparison, the present method for FAC/LDI showed prediction accuracy with about a factor of 2 for high thinning rate data, which needs to be managed with high priority (Fig. 3). In addition, toward easily adapting the models to actual plant piping management, the "FALSET" prediction software was developed, equipped with an essential function for pipe wall thinning management in power plants (Fig. 4) (L11007). With the further verification and improvement of each function, there are prospects for this software to be utilized as a management tool in power plants.

Seismic Evaluation of a Local Wall-thinning Elbow Detected by LDI

The earthquake-proof safety of local wall-thinning elbows with a back side detected by LDI was investigated by the hybrid testing*. No damage was observed in the in-plane and out-of-plane bending of elbows, defected by a 75% condition under the five-times-large amplitude seismic motion of the design-basis earthquake, which expanded the allowable stress level. In addition, torsion buckling occurred, and a wall-through crack was penetrated by cyclic loading under eight times large amplitude due to the abovementioned seismic motion (Fig. 5). The torsion buckling of the out-of-plane bending of the elbow could be demonstrated by finite element analyses and a buckling formula.

*Hybrid testing is a new seismic experiment that incorporates a numerical analysis of the entire structure system with the loading test of a damageconcentrating model.



Fig. 1: Effect of dissolved oxygen concentration on the FAC rate of carbon steel

The FAC rate at 140°C in the solution with a pH of 7 is decreased by the dissolved oxygen of 40-60 ppb. More than 10 ppb of oxygen is effective for FAC suppression in a solution with a pH of 9.2, which simulates PWR secondary water.



Fig. 3: Comparison of the measured and calculated results of thinning rates for an actual power plant (in the case of LDI)

By evaluating the unknown wetness condition using the partial data of thinning rate, the entire thinning rate data can be predicted with an accuracy of factor 2, approximately.



Fig. 4: Display example of the maximum thinning rate profile for a piping system by FALSET

FALSET is equipped with practical functions for management, and residual lifetime can be evaluated with CRIEPI's FAC/LDI prediction model.



(a) Mass flux comparison with the experiment



(b) Distribution of the void fraction around the orifice

Fig. 2: Calculation example of water-steam CFD code (flashing flow around orifice)

The sudden change of void fraction due to flashing around the orifice is calculated robustly, and the mass flux of flashing flow is validated. Utilizing this code, it becomes possible to evaluate flashing erosion in a plant piping system.

*Void fraction: the Fraction of the gas phase volume



Fig. 5: Failure mode of a wall- thinning elbow under an out-of-plane bending condition by hybrid testing (Pipe size; outer diameter is 216.3 mm; wall thickness is 5.8 mm)

In the case of a 75% defect and input seismic motion beyond the eight-times-larger amplitude of the design basis earthquake, which expanded allowable stress level, the torsion buckling deformation with an angle of 45 degrees can be observed. Project Research — Further Improvement of Facility Operations and Maintenance Technologies Deterioration Diagnosis of Instrumentation and Electrical Equipment

Background and Objective

For long-term operation of nuclear power plants, aging of components, piping, and electrical instrumentation equipment is an important issue that should be taken into account. It has been expected that a diagnostic method will be developed to detect such aging.

In case of SCC crack appearance, phased array UT was applied to measure the defect depth sizing on service components such as pipe, core shroud and so on. However, it has been difficult to measure the defect depth sizing on nickel based alloy welds using conventional UT. Therefore, the development of an advanced phased array UT technique is required for nickel based alloy welds.

Long-term integrity of cable insulation was confirmed by tests based on a technical report

published by the Institute of Electrical Engineers of Japan. Especially, the confirmation of integrity (evaluation of material deterioration) of mechanical properties such as the strength and elongation of cable insulation is important, since cable insulation can be degraded due to heating and irradiation stresses. Therefore, it is required to establish an effective index to evaluate the combined degradation of the heat and irradiation of cableinsulating materials.

The objectives of this project are to develop a phased array UT technique for the measurement of crack depth sizing with high accuracy and to construct a model to be able to accurately evaluate the degradation of cable-insulating materials in environments with both heat and radiation combined.

Main results

Application of Phased Array UT for Crack Depth Sizing on Nickel based Alloy Welds

Phased array UT (PAUT) procedure for high performance crack depth sizing on nickel based alloy welds was investigated and proposed. The major advantage of this technique is the improved discrimination capability of noise signals from crack tip signals using twodimensional PAUT (linear array UT) and threedimensional PAUT (matrix array UT) techniques. Phased array UT technique was applied to nickel based alloy welds with SCC cracks. From the examination results, the relation between SCC crack depth through destructive testing and the measured depth by UT showed good agreement (i.e., the sizing error of crack depth approximately being equal to 3 mm) (Fig. 1). From these results, the effectiveness of a phased array UT technique for crack depth sizing on nickel based alloy welds was shown. Therefore, a UT procedure for crack depth sizing was verified.

Investigation of the Degradation behavior of Cable insulating Materials and Devising a New Deterioration Model

The experiments and research conducted so far have made it clear that antioxidants play an important role in the degradation of the mechanical properties of polymeric insulating materials (H10014). However, existing degradation models do not incorporate such antioxidant behavior. For this reason, a new model has been constructed that reflects the socalled "critical concentration characteristics," in which degradation advances below the critical concentration threshold of an antioxidant. This model also involves the application of diffusion equations for oxygen and the antioxidant (Fig. 2). In this way, an attempt has been made to estimate the concentration distribution of the antioxidant and its change over time. The simulation result obtained using this model roughly reproduces temporal changes in the distribution of degradation products, which was observed using a test sheet (Fig. 3). Thus, it has been confirmed that this model is effective in evaluating degradation including estimating the concentration distribution of antioxidants (H11007).



Fig. 1: SCC crack depth sizing using Phased Array UT

The measurement of SCC crack depth sizing with high accuracy on nickel based alloy welds was carried out using Phased array UT technique.



Fig. 2: Constitution of the new degradation model

With this new deterioration model, degradation is evaluated using reaction-rate equations for oxidation reactions that reflect the critical concentration characteristics of antioxidants and diffusion equations.



2 Principal Research Results

experimentally observed and one simulated

edge and central point of the bulk sample, respectively. The experiment was carried out using a thermally accelerated test and was evaluated by the infrared absorbance ratio. lacksquare: before deterioration, A: degraded for 8 hrs at 180°C, ∎: degraded for 44 hrs at 180°C; the solid lines are simulated using the new model in corresponding conditions.

Project Research — Further Improvement of Facility Operations and Maintenance Technologies Disaster Prevention and Maintenance for Hydropower Facilities

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, while the number of such facilities that were constructed more than 50 years ago and their subsequent aging is progressing. In recent years, changes that appear in environments surrounding forests along rivers and reservoirs are remarkable, and the preservation of facility environments including sediment management becomes an important subject. In addition, the number and scale of natural disasters such as earthquakes and rainfalls severely affects hydropower operations. In this project, evaluation and analysis methods for existing dam and spillway gate structures will be established to secure safety against strong earthquakes considering the damaged state of the structures. Also, the total management of watershed-sedimentation techniques that estimate the points/places of sediment yield in dam basins and that observes the behavior of sedimentation and turbidity in rivers and reservoirs will be enacted, along with a simple analysis model that predicts sediment level and turbidity.

Main results

Development of Seismic Performance Evaluation for Aged Dam and Gate Structures

To obtain the basic information of fractures at the contact zone between dams and their foundations, experiments and numerical analyses of concrete gravity dams during earthquakes were studied. Based on those results, a non-linear FEM analytical method considering the damages at dams and their foundations was developed (N11025). Using this method, the earthquake response analysis of actual-size dams was carried out. As a result of the analyses, the relationship between the damage of the dam body (Fig. 1) and the remaining load capacity at seismic performance was clarified, and the evaluation of the seismic safety of concrete gravity dams was suggested (N11026). In addition, a basic procedure for the safety evaluation of dam gates and numerical examples were prepared against strong earthquakes.

2 Evaluation of Predominant Factors in Determining Sediment Yield

We developed an observation system for simultaneously monitoring the kinetic energy of throughfall (V11001), soil splash detachment, surface runoff, and sediment yield to clarify the predominant factors of generating sediment in forests. We found that forest floor cover can contribute to a decrease in soil sediment yield by preventing both soil splash detachment and surface runoff (Fig. 2) (V11030). These results and the landscape, the topographical watershed environment DB that includes information on degraded forest land, and abandoned forests after clear-cutting (V11003) are utilized for the evaluation of the turbidity and sediment in the reservoirs of dams using our water circulation model.

Furthermore, an analytical method was constructed that could evaluate slope stability by simulating heavy rainfall infiltration into the ground to estimate the hazard of slope failure with a large volume of earth and sand caused by pore water (Fig. 3).

3 Development of an Evaluation Method for Current and Sediment in Rivers and Reservoirs

In order to investigate the current profiles and processes of sedimentation in rivers and dam reservoirs, a movable current and topography measuring system that is equipped with a Acoustic Doppler Current Profiler (ADCP), an echo sounder, and Global Positioning Systems (GPSs) were developed and applied to the strong currents near the hydraulic structures (Fig. 4). In addition, in order to predict flood discharge and sedimentation in rivers and dam reservoirs, C-HYDRO 2D, which can calculate twodimensional horizontal flow and topography, was combined with a prediction model of rainfall intensity and discharge (NuWFAS and HYDEEMS).



Fig. 1: Analyzed result of seismic damages of concrete gravity dams

The non-linear seismic response analysis of dam considering damages in dam body, contact zones between dams and foundations, and basement rock was carried out. It can be possible to evaluate the seismic damage condition and degree according to the characteristics of dams. For the case of dam crests at 100 m in height, the damage of high elevation in a dam body becomes severe, as the seismic response of a dam apex is hard. In the case of a dam crest a 50 m in height, the damage of the foundation becomes severe, as the seismic response of the dam apex is soft compared to the case of a dam crest at 100 m in high.



A slope with forest floor that is not sufficiently covered with either litter or understory vegetation (Japanesecypress)

Fig. 2: Schematic diagram of a system for the monitoring of soil erosion rates

Monitoring for 15 months found that sediment yield was 15.6 times higher in a slope with sparse forest floor cover (Japanese cypress) than in a slope with dense forest floor cover (Konara oak). We developed a system for simultaneously monitoring the kinetic energy of throughfall, soil splash detachment, and detached soil sediment transported downward by surface runoff. This enabled us to determinate soil erosion rates in the forested slope.



40 60 80 100 120 140 160 180 200 220 24 Velocity (0.0 -0.5 1.0 depth (m 1.5 2.0 Water 2.5 3.0 Movable current of river bed 20 25 and topography 3.5 -10 15 measuring system Distance (m)

Fig. 3: Examples of an analytical evaluation for the slope stability of slips

The location of slip failure in a slope was estimated by calculating heavy rainfall infiltration into the ground and slope stability by using the change of water saturation and water level in the ground. These figures showed that the depth of the rainfall infiltration corresponded largely to the location of slip failure.

Fig. 4: Movable current and topography measuring system

The left figure shows an appearance of the observation in front of the inlet of a hydroelectric power plant using the movable current and topography measuring system. The right figure shows the measuring results that consist of the vertical velocity profile and a riverbed feature. Project Research – Further Improvement of Facility Operations and Maintenance Technologies Integrated Remaining Life Assessment Technology for Inspection, Prediction, and Monitoring

Background and Objective

Aged thermal power plants, which have achieved a cumulative operation time exceeding 100,000h, account for approximately 80% of the thermal power plants in Japan. The damage of equipment subjected to high temperatures in aged thermal power plants, which have achieved a cumulative operation time exceeding 200,000 h in particular, has become obvious and is a cause for concern. At ultra-supercritical pressure steam power plants with high thermal efficiency, various troubles caused by creep damage have occurred at the welded heataffected zone (HAZ) of high chromium steel steam pipes, such as 9Cr steel pipes. Thus, highly reliable remaining life assessment technologies for facilities are becoming increasingly important to safely and rationally operate and manage these power plant facilities.

In this project, we aim to further advance two technologies: 1) an advanced nondestructive testing technology using ultrasonic waves, and 2) an analysis technology to predict the progress of damage with high precision, both of which have been developed by CRIEPI. We also aim to establish an integrated remaining life assessment technology for facilities based on the characteristics of these two technologies.

Main results

Development of Technology for Estimating the Shape of Weld Metal

Precise data on the shape of weld metal is necessary to appropriately evaluate creep damage, as the development of creep damage in the welded portion is affected by the shape of the grooves in the welded joints. We developed a method of nondestructively estimating the shape and width of weld metal, including re-welding, by measuring ultrasonic waves scattered at the welded portion (Fig. 1).

2 Estimation of Temperature History during Welding

It is necessary to quantitatively predict the complicated temperature distribution and temperature history under the welding process to accurately evaluate the strength of a material subjected to multilayer welding. Therefore, we determined the shape of the molten portion by performing a welding simulation on the basis of temperatures measured during the welding of 9Cr steel (Fig. 2). The application of the shape data in the molten portion to the welding simulation enables us to estimate the widths of the HAZ and the temperature history of each measurement point in the welded joint of large-diameter 9Cr steel pipes.

3 Evaluation of the Creep Strength of Longitudinal Welded Pipes under Internal Pressure Conditions

Internal-pressure creep tests were carried out using many small-diameter longitudinal joint tubes (outer diameter: 60 mm) and a pipe specimen with the dimensions of actual equipment (outer diameter: 686 mm). The results indicate that the creep rupture life of the tubes under internal pressures tends to be equivalent to or shorter than that obtained by a uniaxial creep test (Figs. 3 and 4). Also, a large number of voids, a type of creep damage, were generated inside a thick pipe rather than on its outer surface. In addition, although the deformation of the pipe specimen with the dimensions of actual equipment was small before its rupture, the specimen rapidly broke with significant deformation along with the formation of a through crack at the HAZ of the longitudinal welded pipe (Fig. 5).

Proposal of a Method for Evaluating Creep Rupture Life

We proposed a method for evaluating the creep rupture life of high-chromium steel longitudinal welded pipes on the basis of the development of damage at the welded portion as revealed by the experiment and analytical investigation. This method can consider the effect of stress multiaxiality on the creep damage. The proposed evaluation method was applied to the results of creep tests on 9Cr and 12Cr steel tubes and pipe under the application of internal pressure. The creep rupture lives of the longitudinal welded specimens were estimated with high precision, demonstrating the validity of the proposed method (Fig. 6).





- material material
- (a) Photograph of the cross section of the actual specimen
- (b) Ultrasonic image of the cross section

Fig. 1: Estimation of the shape of weld metal

It is possible to estimate the shape and width of weld metal within an error of 2 mm by measuring the ultrasonic waves scattered at the welded portion (material, 9Cr steel).



Fig. 2: Welding simulation of 9Cr steel

The complicated temperature history and the temperature distribution as a result of multiple passes of shielded metal arc welding are quantitatively reproduced.



Fig. 3: Results of creep test of 9Cr steel welded joints



Fig. 4: Results of creep test of 12Cr steel welded joints



Fig. 5: Photograph of a ruptured 9Cr steel pipe with the dimensions of the actual equipment (Temperature, 650°C; rupture time, approximately 8,600 h)



Fig. 6: Results of applying the proposed method to evaluate creep rupture life

Project Research — Further Improvement of Facility Operations and Maintenance Technologies Operation and Diagnosis of Aged Power Apparatuses for Substations and Underground Power Transmission Lines

Background and Objective

Recently, the management and maintenance of aged power apparatuses have become an urgent issue for the electric power industry, and cost reduction including running cost, repair cost, and renewal cost is also an important issue. Within these last several years, huge numbers of power apparatuses, which were manufactured and installed during the rapid economic growth periods in Japan, seem to be reaching the end of their expected life. Based on such a situation, this research project aims mainly at two items. One is to develop on-site diagnosis methods of aged power apparatuses, while the other is to provide a user-friendly decision support tool for maintain aged power apparatuses. For these objectives, the research project aims at the development and practical utilization of on-site

deterioration diagnosis techniques for the main apparatuses of power transmission and distribution systems. As the main apparatuses, power transformers of 66 kV to 275 kV class, XLPE cables of 22 kV to 66 kV class, and GIS (gas-insulated switchgears) are selected. On the other hand, the research project aims to establish optimal criteria to determine renewal time as well as to develop rational and reliable maintenance decision support programs for aged equipment based on the actual maintenance cost data of such apparatuses. In addition to those main apparatuses stated above, the project also aims to develop an evaluation method of coating layer degradation as a common issue of power apparatuses.

Main results

Development of On-site Insulation Degradation Diagnostic Methods for Power Apparatuses in Substations and Underground Transmission Lines

A diagnostic method for the thermal deterioration of the insulation paper of transformers has been proposed. The method utilizes basically only the load history of the transformer, and the method has been applied to distribution transformers (66-kV class) up to extra-high voltage transformers (275-kV class). The estimation error of the degree of polymerization of the insulation paper based on this method was found to be practically acceptable ($\pm 10\%$) as shown in Fig. 1 (H11026). As for the abnormality diagnostic method of a transformer winding, a transfer function obtained by a frequency response analysis (FRA) is utilized, and an abnormal part of an actual transformer winding structure can be estimated as shown in Fig. 2 (H11027). In addition, a partial discharge recognition technique has been improved to detect minute water tree degradation in removed XLPE power cables in order to establish a XLPE power cable degradation database for future use, and a new on-site diagnosis method for aged XLPE power cables has been proposed based on a dumped oscillating wave voltage source (H11031). Furthermore, a new diagnosis method to detect the abnormality of gas-insulated switch gears (GIS) has been proposed based on an analysis of absorbed byproduct gases from partial discharge.

2 Development of Decision Support Programs for the Maintenance and Renewal of Power Apparatuses

In order to develop decision support tools for making rational renewal and update plans for aged power apparatuses, a support program for a single apparatus such as a transformer and a gas-insulated breaker (GCB) has been proposed by minimizing the average annual maintenance cost for such apparatuses based on the actual maintenance costs. Through the experience of developing those programs, more complicated programs for multicomponent apparatuses such as gas-insulated switch gears (GIS) and overhead transmission lines have been developed. On the other hand, an estimation program has been proposed in order to compare the difference of the averaged annual maintenance cost based on the different maintenance strategies and to estimate the effect of life estimation accuracy of a given diagnostic method as shown in Fig. 3 (H11032).

3 Development of an Estimation Method for Coating Layer Deterioration

In order to develop an estimation method for coating layer deterioration for power equipment such as transmission towers, a long term accelerating aging test has been carried out using typical coated steel plates with a molten zinc primary coat and an epoxy resin secondary coat. The plates were set in three different inclinations, namely, horizontal, a 45° inclination, and vertical. The test continued for 55 months, and the results showed that the horizontal setting has the fastest degradation and that the coating impedance can detect a faint difference of degradation with higher sensitivity than surface observation by human eyes.

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Fig. 1: Comparison between the measured and estimated averaged degree-of-polymerization of oil-impregnated insulation papers in 66–275 kV power transformers

We found good agreement between the estimated averaged degree of polymerization and that measured for 24 66-275 kV power transformers. The average error of the estimation was found to be less than 10%.



Fig. 2: Measured and calculated transfer functions

We tried to develop an equivalent circuit to obtain a theoretical transfer function based on the structure and actual sizes of each part of a 66-kV power transformer. As shown in the above figures, the peak positions of the measured and calculated transfer functions are similar to one another. With this result, there seems to be clear possibility to develop a method to correlate the peak frequency change of a transfer function and the coil abnormality. For example, the peak frequency of a transfer function at about 7.22 kHz in the figure is found to be shifted according to the distance change between the primary winding and the secondary winding.



Fig. 3: Sample display of a program to compare long-term effect under different maintenance strategies

This program can compare the long-term effect of different maintenance methods on the average maintenance cost. The methods to be compared are CM (corrective maintenance), TBM (time-based maintenance), and CBM (condition-based maintenance) based on several types of input information, such as equipment age distribution and expected life time probability. It can evaluate the annual and average maintenance cost during the operation period of the equipment. This program uses a graphical user interface and is designed to be easy in utilization for staff responsible for devising maintenance strategies and developing diagnosis techniques. The sample calculation in the sub-figure at the lower right corner shows that TBM and CBM are more expensive than CM before 40 years of operation, but after that, CBM has the lowest maintenance cost among those methods.

Project Research — Further Improvement of Facility Operations and Maintenance Technologies Development of Simple Method for the Cleaning of PCB-contaminated Transformers

Background and Objective

PCB contamination in insulating oil for electric facilities such as transformers was made public in 2003. Due to the abundance of contaminated facilities, an effective technique for the removal of PCBs from a contaminated transformer as well as PCB analysis has been required. The major

objectives of this study are the development of a biosensor that can rapidly measure PCBs in oil in a cost-effective manner and a simple process to remove PCBs from contaminated transformers using circulative and energizing cleaning techniques.

Main results

Development of Onsite Measurement Using a PCB Biosensor*

A prototype vehicle for onsite PCB measurement equipped with analytical instruments was developed (Fig. 1). The time needed to measure the PCB concentration of an insulating oil sample is three hours, and parallel operation enables the onsite measurement of 60 samples a day. This onsite measurement is useful to assess PCB removal progress from contaminated transformers during the cleaning process.

2 Onsite PCB Removal Experiment for Large-size Contaminated Transformers

Onsite experiments for removing PCBs from a transformer by using circulative and energizing cleaning techniques were carried out in cooperation with 10 power companies, J-Power, and the Japan Atomic Power Company. A prototype mobile facility for the circulative cleaning of large size transformers, with oil capacity between 8 KL and 20 KL, was developed (Fig. 3). The mobile facility for circulative cleaning was successfully operated at two feasibility test sites. The energizing cleaning test has been undertaken at three sites, and the experimental results are reported to the PCB Treatment Technology Council of the Ministry of the Environment.

3 Confirmation of PCB Removal Efficiency

PCB removal efficiencies in transformers on onsite for both the circulative and energizing experiments were evaluated by measuring residual PCBs in assemblies inside transformers after finishing cleaning. PCB removal rates ranged from 96.2% to 99.7%, demonstrating the high performance of both techniques to remove PCBs in large transformers.



Fig. 1: Prototype vehicle for PCB analysis (left) and analytical instruments inside the vehicle (right)

A centrifugal concentrator, a table-type draft chamber, and a temperature control unit were installed into the vehicle to ensure analytical accuracy matching that of laboratory analysis. Analysis is possible without an external power supply.



Fig. 2: Image and outline of circulative and energizing cleaning techniques for PCB-contaminated transformers



Fig. 3: Prototype mobile facility to remove PCBs by using a circulative cleaning technique

The facility consists of the A and B units. The heating and circulation of cleaning oil with the heater and pump are conducted in unit A. Unit B consists of equipment for monitoring and controlling the flow rate and temperature with vent treatment.

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Expansion of Fuel Types and the Improvement of Efficiency in IGCC

Background and Objective

Coal gasification combined cycle (IGCC) power generation, which is a highly efficient system and which has an advantage regarding environmental protection, is an important technology for electric power companies as an option for next-generation coal-based thermal power plants. CRIEPI has been involved in the research since the initial stage of IGCC development, and has been supporting the design and operation of the Nakoso IGCC demonstration plant. Aiming at the development of a commercial IGCC plant and also to support the operation of the demonstration IGCC plant, we have developed gasification technology for many types of coal and a hot-gas cleanup system to improve fuel flexibility, thermal efficiency, and plant reliability etc.

Main results

Supporting Activities of the IGCC Demonstration Project

The gasification reactivity of sample coal was clarified in high-temperature and elevatedpressure conditions that are similar to the actual conditions of a gasifier. The gasification performance of the IGCC demonstration plant was predicted for sample coal based on the analytic results of the gasification reaction rates and on our one-dimensional numerical simulation technique, in order to discuss the operating conditions of the demonstration plant (Fig. 1). Furthermore, the results of the demonstration tests were expressed well by our threedimensional numerical simulation technique, which could solve complicated phenomena in a gasifier. This supporting tool to evaluate the gasification performances of large-scale and commercial-scale gasifiers by the numerical simulation was verified for various operating conditions, such as for coal with remarkably high reactivity, as well as for coal blending.

2 Evaluation of the Availability of Biomass as a Blended Fuel for a Coal Gasifier

To expand the fuel types of the IGCC, the ash-melting characteristics and gasification characteristics of blended fuels, which consist of a mixture of coal and wooden biomass or sewage sludge carbonized fuel, were evaluated. It became clear that mixing the coal, which has a high ash melting point, and the sewage sludge carbonized fuel would cause a big drop in the ash melting point* relatively, while also promoting the gasification reaction (Fig. 2), as the sewage sludge carbonized fuel has high alkali content and a low ash melting point. The findings from this study indicated possibilities for the further expansion of the available types of coal for the IGCC.

3 Evaluation of Thermal Efficiency and Proper System Configuration for a Hotgas Cleanup System

The process design of the hot-gas cleanup system, which removes halides and mercury, was conducted to achieve a higher thermal efficiency of the IGCC and simple system configuration. The new system was derived by improved design to decrease power consumption in the sulfur removal process and to minimize the instruments for the halide removal process (Fig. 3). The efficiency of the system was analyzed for the commercial-scale plant equipped with a gas turbine of 1500°C TIT. The net thermal efficiency of the IGCC plant is expected to increase by 1.6 % (HHV) in absolute value due to the decreased the thermal loss and the lower auxiliary power.



Fig. 1: Outline of the 1D numerical simulation of a gasifier and the prediction of gasification performance

The gasification performance at full load was predicted with the one-dimensional numerical simulation technique using the coal properties and the experimental results of the gasification reaction rate analysis. The prediction of the char production ratio, which is one of the gasification performance indicators to evaluate the operation of the gasifier, is shown in the right figure.



Fig. 3: System configuration of the proposed dry gas purification system

This gas purification system consists of dry gas removal processes for halide, sulfur, and mercury, followed by the filtration of remaining dust. The system was improved by reducing auxiliary power for the sulfur removal process and through simplified instruments for halide removal.

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Utilization of Low-grade Fuel

Background and Objective

The diversification of fuel species such as subbituminous coal, the advanced management of boiler tube surfaces, and the improvement of environmental preservation are necessary to keep coal-fired power plants in good working order. In this research subject, a combustion method to increase the blend ratio of sub-bituminous coal in bituminous coal and an estimation method for the grindability of sub-bituminous coal are developed. For the advanced management of boiler tube surfaces, the clarification of the characteristics of hydrogen sulfide (H₂S) formation and the development of a coating technology to prevent sulfidation corrosion are advanced. Furthermore, the factors affecting the behavior of ash deposition on the tube surface are studied to prevent fouling and slugging. To improve the environmental preservation, countermeasures to trace elements in coal-fired power plants are studied.

Main results

Increase of the Sub-bituminous Coal Blend Ratio and the Estimation of Subbituminous Coal Grindability

The blend ratio of sub-bituminous coal could be increased up to 75% by adjusting air injection conditions such as the flow rates of primary, secondary, tertiary air at the burner, including staged air, through the use of a pulverized coal combustion test furnace at CRIEPI (Fig. 1) (M11022). On the other hand, the grindability of coal could not be evaluated by simple HGI* when the adherent moisture content on the surface of the coal is high. Therefore, the advanced method modified with adherent moisture content was proposed (Fig. 2) (M11016).

2 Advanced Management of Boiler Tube Surfaces

(1) H₂S formation characteristics

The organic sulfur and pyritic sulfur in coal were readily released to the gaseous phase and formed H₂S in the pulverized coal combustion field. The amount of sulfur released could be estimated by the analysis of the forms of sulfur in the coal (Fig. 3). The sulfur-release area in the co-firing of subbituminous coal moved to the downstream region due to the ignition delay of the coal (M11003). A numerical simulation model for the H₂S formation characteristics was developed from these results and was validated by the experiments of the pulverized coal combustion test furnace (Fig. 4) (M11020).

(2) Countermeasure for preventing sulfidation corrosion

The corrosion amount is estimated using the equation of the sulfidation corrosion rate that was derived for a laboratory corrosion test. The estimated corrosion amount showed good correlation with the corrosion amount of the water wall tube in a thermal power plant. Our coating technology for the prevention of sulfidation corrosion was improved in durability, and the durability of the coating is now under testing at some thermal power plants.

Improvement of Environmental Preservation at Coal-fired Power Plants

The prevention of oxidation from Se^{4+} to Se^{6+} by the addition of Mn^{2+} into the liquor of flue gas desulfurization (FGD) contributes to a decrease in cost for the wastewater treatment of FGD. The experiment results using the FGD unit in our coal combustion test facility revealed that the oxidation of Se⁴⁺ was prevented by retaining the Mn^{2+} concentration in FGD liquor (Fig. 5).

^{*}HGI: Hardgrove Grindability Index; HGI is the index of the grindability of coal. It is known that HGI is related to the grinding work index, which is used to estimate power consumption at mills.



① The ignition position moves downstream with the increase of a primary air flow rate.



② Ignition becomes stable by decreasing the two-stage combustion ratio and increasing the ratio of the secondary air flow rate to the tertiary air flow rate.



③ The ignition also becomes stable by decreasing the burner load from 100% to 85%.

Fig. 1: Combustion flame at 75% of the blended ratio of sub-bituminous coal

It was clarified that the ignition became stable by adjusting the air injection conditions of the burner. Furthermore, it was found that the decrease of burner load from 100% to 85% enabled stable ignition.



Fig. 2: Correlation between the actual grinding work index and the estimated grinding work index

The grinding work index for a roller mill can be estimated from the HGI and the adherent moisture content on the coal surface.



Fig. 4: Distribution of hydrogen sulfide along the central axis of the coal combustion test furnace

The numerical calculation of hydrogen sulfide concentration between the burner and the two-stage combustion air ports is qualitatively in good agreement with the experimental result.



Fig. 3: Influence of sulfur form on the sulfur-released ratio

The organic sulfur and pyritic sulfur in coal are readily released to the gas phase compared to the sulfate sulfur. Such sulfur is converted into H_2S in the pulverized coal combustion field.



Fig. 5: Prevention of the oxidation of Se⁴⁺ by the addition of Mn²⁺

The oxidation of Se⁴⁺ to Se⁶⁺ by S₂O₈²⁻ is prevented in the presence of Mn^{2+} because S₂O₈²⁻ oxidizes Mn^{2+} selectively instead of Se⁴⁺ in FGD liquor.

2 Principal Research Results

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power Advanced Utilization Technology of Biomass and Waste

Background and Objective

As an effort toward reducing CO₂ emissions, the use of biomass for power generation is expected. Due to the difficulty in collecting a large amount of biomass, it is important to plan a business model appropriate to the potential. Since the calorific value of biomass is generally low due to the high moisture content of biomass, the development of biomass utilization technologies including upgrading technologies is a critical issue. In this project, the evaluation technology of biomass potential and the utilization technology of biomass

energy are developed. The evaluation technology of biomass potential is meant to assist planning of the biomass energy project. The utilization technology of biomass energy consists of upgrading technology based on coal combustion and gasification technologies that have been developed by CRIEPI. The aim of the development is to increase the use of biomass energy. The targets cover the various sorts of biomass, from woody biomass such as that from forest thinning to waste-derived biomass such as sewage sludge.

Main results

Evaluation Technology of Biomass Potential: Potential of Biomass Power Generation in the Tohoku Region

The potential of waste power generation in Japan and the LCA-CO₂ of the coal-fired power plants in Japan and abroad were evaluated (Y10010). The amount of biomass waste (combustible rubble, agricultural, and forestry waste) generated from the earthquake disaster reconstruction process of the Tohoku region was estimated using the evaluation method. The power generation potential of the biomass waste

was evaluated considering the progress of rubble treatment and the recovery of agriculture and forestry. In the case where the reconstruction plan proceeded smoothly and where the biomass was used as fuel for power generation in the Tohoku area, the electric energy reached 418 GWh/y. This value is equivalent to one-half of the new energy output (851 GWh/y in FY2010) of Tohoku Electric Power Co. (Fig. 1) (Y11019).

2 Upgrading and Utilization Technology of Biomass

2-1. Co-combustion and Gasification Characterization of Carbonized Sewage Sludge*

The co-combustion test of carbonized sewage sludge and coal was carried out using the coal combustion test facility. The co-combustion characteristics of carbonized sewage sludge and coal was approximately equivalent to the monocombustion characteristics of coal (Fig. 2). The gasification test of carbonized sewage sludge was carried out using the carbonized gasification test facility. It was difficult to discharge the ash as molten slag, and it was difficult to keep the calorific value of synthesis gas at 3.3 MJ/Nm³ or more. The co-gasification test of the mixture of carbonized sewage sludge and low-ash woody biomass showed stable discharge of molten slag and kept the calorific value of synthesis gas at 4.7 $MJ/m^{3}N$ or more (Fig. 3).

2-2. Development of a Test Apparatus for the Carbonizing Characterization of Biomass

To estimate the carbonization characteristics of biomass, a small-size carbonization test apparatus (fuel feed rate of 1 kg/h) was developed. The carbonizing test of pine pellets (carbonizing temperature range of 300-600°C) showed that the char yield was in good agreement with that of the batch-type carbonizer (fuel feed rate of 50 kg/h). Since this apparatus enables the quantitative analysis of the non-condensable components and sampling of all the condensable components in pyrolysis gas, it can be used predict the carbonizing characteristics of biomass in a commercial carbonizer (M11014).

*Collaborative research with Bio Fuel Co.



Fig. 1: Evaluation result of biomass power generation potential

Figure 1 shows the biomass power generation potential when the estimated amount of biomass generation is treated with the general waste treatment facility with the power generation system in the Tohoku region (completing the treatment in about eight years). Agricultural waste refers to agricultural residue from when the recovery of agricultural land goes smoothly. Forest waste refers to that derived from wood residue and forest thinning when the recovery from the forest industry proceeds smoothly, and the use of domestic lumber is increased. The combustible rubble and agricultural waste are produced in Iwate, Miyagi, and Fukushima prefectures, and the forest waste is produced in the six Tohoku prefectures and in Ibaraki Prefecture.



Fig. 2: Co-combustion test result of carbonized sewage sludge and coal

Figure 2 shows the NO_x levels in incinerator flue gas and the concentration of unburnt carbon in ash in a co-combustion test of the two types of carbonized sewage sludge and coal. This carbonized sewage sludge was produced by different production methods of carbonization. The NO_x levels and concentrations of unburnt carbon in ash were almost equivalent to that of the mono-combustion test of coal. The key words "kiln" and "fluidized bed" in the figure refer to the types of carbonizers used for the production of carbonized sewage sludge.



Fig. 3: Gasification test result of carbonized sewage sludge and pine

Figure 3 shows a relationship between the oxygen ratio and the calorific value of synthesis gas in the gasification test of the carbonized sewage sludge and the mixture of carbonized sewage sludge gasification, it was difficult to reduce the oxygen ratio to less than 0.43. When the oxygen ratio was reduced, the temperature of the gasifier went down. In case of the mixture gasification, the gasifier kept its temperature high at the oxygen ratio 0.36, and the calorific value of synthesis gas reached about 4.7 $MJ/m^{3}N$.



Fig. 4: Comparison of the char yield

As the carbonizing condition of the small-size carbonizing test apparatus, the carbonizing temperature is set at the range of 300-600°C, the residence time in the carbonizer at 15 minutes, and the fuel feed rate at 1.0 kg/h. As to the large-size batch-type carbonizer, the carbonizing temperature is about 350-425°C, the residence time is 15 minutes, and the fuel feed rate is 50 kg/h. Both results showed good agreement in char yield.

2 Principal Research Results

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power Thermal Power Generation Systems with CO₂ Capture

Background and Objective

The reduction of CO₂ emissions in coal thermal power generation for global warming control is an important matter for electric utilities. Therefore, high-efficiency technology and biomass utilization are promoted for some power generation systems. Attention is paid to CO₂ Capture and Storage (CCS) as one of the effective countermeasure against global warming in recent years. In Europe and the United States, many CCS projects have been announced. However, the current CCS technology exhibits many problems, such as a significant drop in power generation efficiency and an increase in cost.

To offer a futuristic option that solves these problems, CRIEPI has proposed a highly efficient IGCC system with CO₂ capture (Fig. 1). In this project, we will develop O₂-CO₂ blown gasification technology and semiclosed GT technology.

Main results

Effect of Enriched CO₂ on Gasification Reaction Promotion in a Bench-scale Coal Gasifier*

In an O₂-CO₂ blown gasifier, a gasification reaction promotion by enriched CO₂ can be expected. On the other hand, a drop in the temperature in the gasifier is a problem because CO₂ has a higher molar-specific heat. CO₂ was used for a carrier gas component in our 3 t/day bench-scale coal gasifier, and the combustor temperature was held constant, adjusting the oxygen concentration in the gasifying agent, to examine the gasification characteristics (Fig. 2). As a result, the carbon conversion efficiency was improved at a high CO_2 concentration when the temperature in the gasifier was properly maintained by adjusting the oxygen concentration in the gasification agent (M11019).

Numerical Modeling of O₂-CO₂ Blown Coal Gasification

An O₂-CO₂ blown coal gasification reaction model was developed and validated to be utilized in the process of the design and optimization of a practical-scale O₂-CO₂ blown gasifier. Modified char gasification and water-gas-shift reaction models were developed and implemented with CRIEPI's three-dimensional CFD code, which had already been validated through air-blown gasification experiments. In comparison with the experimental results* of the 3 t/day gasifier (Fig. 3), it was confirmed that the model presented here could capture the general feature of gasification characteristics (Fig. 4) (M11017).

3 Combustion Promotion in Oxy-fuel Semiclosed Cycle Gas Turbines

The oxy-fuel IGCC (Fig. 1) employs a semiclosed-cycle gas turbine system, in which CO-rich coal gases are burnt with oxygen under stoichiometric conditions and diluted with recirculated gas turbine exhaust to adjust the combustor exhaust temperature. Since the higher combustion efficiency without supplying excess oxygen was required for the gas turbine in order to realize the high thermal efficiency of the IGCC system, the combustion promotion was studied using numerical analyses based on reaction kinetics. As a result, it was found that, the combustion efficiency was improved with increase of the fuel oxidation rates when the dilution gas of recirculating exhaust was divided into two parts, one was supplied into a burner at a suitable gas flow rate and the other was supplied into a combustor downstream as a secondary dilution (Fig. 5) (M11004).





Fig. 1: Concept of a highly efficient oxy-fuel IGCC with CO₂ capture

This novel system consists of an O_2 - CO_2 blown gasifier and a semiclosed GT with exhaust CO_2 circulations. It is expected to have higher thermal efficiency (more over 40%: HHV Net) and a simpler configuration, compared with the existing IGCC with CO_2 capture.



Fig. 2: Gasification testing conditions and the CO₂ feeding method

 CO_2 was used for coal and/or char carrier gas in a combustor, and the O_2 supplied to the combustor was adjusted, maintaining the air ratio so that the combustor temperature became constant.



Fig. 3: Comparison of model results with experiments in the 3 t/day gasifier

The presented model could accurately estimate the gasification characteristics.



Fig. 4: Distributions of CO concentration

CO concentration in the O_2 - CO_2 blown condition drastically increased at high CO_2 concentration in the gasifying agent.



Fig. 5: Combustion promotion by dilution gas streamwise splitting

The combustion efficiency could be improved both by adjusting the primary dilution gas/fuel molar ratio to approximately 3 and by supplying the secondary dilution downstream to maintain the combustibility in the primary combustion zone.

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Basic CO₂ Storage Technology Development Considering Geological Structure in Japan

Background and Objective

For preventing global warming, many countries consider the introduction of CCS, which recovers CO₂ from CO₂ emission plants and storage it underground. However, the implementation of CCS has not been made in most countries yet, because there are many unsolved problems regarding economy, CO₂ storage technology development, carbon tax, and the obligations of CCS itself. In this project, we collected and analyzed information regarding the latest CCS activities in Japan and the world, studied the phenomenon, and developed basic technologies for CO_2 underground storage, considering geological conditions near the coast where many large CO_2 emission sources are located.

Main results

Basic CO₂ Underground Storage Technologies Considering Geological Structures in Japan

Geological structures in coastal areas where large CO₂ emission sources are characterized by a gently declining slope from inland out towards the sea. We proposed flows for investigating a CO₂ storage candidate site and for evaluating faults (Fig. 1). We improved the numerical performance simulation method by introducing a two-phase flow evaluation method.

We applied these flows and performance evaluation technology to the CO₂ storage candidate site of ZeroGen (responsible organization of an Australian CCS project) in order to construct a geological and hydrological model and to predict CO_2 migration performance by injecting 1 million tons of CO_2 into a well (Fig. 2). The field tests showed that the CO_2 injection pressure was higher than the estimated pressure; therefore, the CO_2 injection cost is estimated to be very high, and the ZeroGen project was thus cancelled. We learned that reliable site evaluation is necessary to observe accurate particle size distribution and the heterogeneity of permeability distribution in the reservoir layers (N11003) (conducted in collaboration with ZeroGen).

2 Development of CO₂ Monitoring Methods in the sea

As CO₂ storage sites may be located under the sea in Japan, we proposed an sea-based CO₂ monitoring system, integrated with: an acoustic tomography method, sea robots (AUVs) without cables and so on, as a leakage detection system for during and after CO₂ injection (Fig. 3)

(some parts of the research funded by RITE). We also developed a numerical simulation method that can predict CO₂ diffusion in the sea in case of CO₂ leakage occurring during transportation and injection and after injection.

Study of CCS Research Trends and CO₂ Transportation and Injection

According to a study of CCS policy and trends regarding technology development, we pointed out that public acceptance is most important. Some examples showed that large-scale CCS projects were cancelled due to the objections of local residents (V11006) (conducted by request from the Federation of Electric Power Companies). We also showed that CO_2 transportation and injection into under the sea floor by ships with CO_2 injection pumps and flexible pipes is more advantageous than pipe lines in some cases (conducted in collaboration with the University of Tokyo).



Fig. 1: CO₂ storage candidate site evaluation flow

It is necessary to integrate the evaluation of accurate geological information and characteristics for the reliable estimation of the seal layer and reservoir.



Fig. 2: Application of the performance prediction method to a CO₂ storage candidate site of ZeroGen

We constructed a geological and hydrological model using the evaluation flow with geological information and core samples from ZeroGen. We estimated the CO_2 migration area by injecting 1 million tons of CO_2 for 30 years into a well.



Fig. 3: CO₂ monitoring system in the sea Left: CO₂ sea monitoring flow; right: CO₂ sea monitoring overview

Monitoring will be conducted through a process aimed at the detection of CO₂ leakage using an acoustic tomography method, including a search of the CO₂ leakage point using AUVs (robots without cables) and the continuous monitoring of CO₂ leakage conditions using a towed observation system.

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Integrated Operation and Control Techniques for Supply and Demand in Autonomous Demand Area Power Systems

Background and Objective

The penetration of distributed power generation (DG), in particular, photovoltaic (PV) power generation, is expected to be accelerated to cope with global environmental problems, etc. To achieve the secure operation of a utility grid and to maintain appropriate power quality with a large penetration of DG, the development of integrated operation and control techniques for supply and demand, i.e., DGs and demand appliances at the customer side, is expected to be effective in addition to the improved

operation and control of an electricity distribution system.

The objective of the project is to develop an integrated operation and control methodology for supply and demand in Autonomous Demand Area Power Systems (ADAPSs) to achieve the smooth introduction and utilization of DG through renewable energy.

Main results

Development of a Comprehensive Analysis Tool for Power Distribution Systems

In order to cope with issues actualized in recent years, such as voltage rise in distribution lines caused by the interconnection of PVs and capacitors for power factor improvements (SC) of middle-voltage (MV) customers, a comprehensive analysis tool for a distribution system that supports clarifying the phenomenon and planning measures of various issues in a distribution system was developed. The tool can create a system circuit model easily by using a graphical user interface (GUI) on a general-purpose PC, in addition to using control equipment on the system side, such as a automatic voltage regulator (SVR) and reactive power compensation equipment (SVC), and the voltage control function of DG and the SC connection/ disconnection function of the customer side can be imitated. Moreover, the time variation of the current and voltage of MV and LV systems can also be clarified (Fig. 1) (R11025).

2 Evaluation of the Impact of the Large Penetration of Residential PV Systems with Three-phase Imbalances on the Voltage Management of Distribution Systems

For the cases in which large-capacity singlephase equipment such as PVs is largely connected, the impact on voltage imbalance between three phases was analyzed. The results show that voltage regulation by SVC controlling the three phases together becomes difficult. It is also clear that the number of customers, at which output power PV is restrained by a voltage control function, increases notably when the penetration rate exceeds 40% (Fig. 2) (R11026).

Development of an Operation Method for ADAPS for Utilizing the Surplus Power of an Entire Power System Due to PV Systems by Using a Heat Pump-type Water Heater and an Electric Energy Storage System

Suppressing PV generation is considered a measure for surplus power caused by the large penetration of PV systems and the shortage of storage capacity of an electric energy storage system. A determination method for the output power limit of a PV that minimizes the suppressed energy of the PV in an entire distribution system is thus proposed. The method applies the daytime operation of a heat pumptype water heater (HPWH) and maintains constant reverse power energy for each customer, by which the absorbed energy of the electric energy storage system is kept constant (Fig. 3, 4). Simulation results validate that the proposed method reduces the suppressed energy of PVs effectively (Fig. 5) (R11030).



Fig. 2: State of three-phase imbalance versus the maximum difference of line voltage and the rate of the consumer controlling PV Voltage unbalance and PV output power reduction increase according to the increase of the PV three-phase imbalanced connection rate.





Simulation conditions



Fig. 5: Reduction effect of the rate of the suppressed energy of the entire distribution system (average of suppressed days)

The suppressed energy of the PV is reduced effectively by introducing the proposed method and by operating HPWHs.

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Next-generation Communications Network Systems

Background and Objective

Utility communication network systems have been well implemented for the automated operation of power generation and delivery, but have yet to be developed for customer communications including smart metering, and power asset maintenance and diagnosis. In addition, communications for power system protection are still proprietary and legacy (not IP-based). This project deals with the integration of fundamental technologies developed in the previous project and the development of design methods and tools for: demand-area secure communications networks interconnecting customers and distributed energy resources, sensor networks for power asset condition monitoring, and IP-based wide-area and high-speed control networks.

Main results

Development of Transmission Performance Assessment and Design for a Demand-area Network

We measured radio propagation characteristics in both a "concentrator to meter" and "meter to meter" communication environment for smart meter multi-hop wireless communications and developed an empirical formula to estimate the propagation path loss, which can be applied in radio cell planning at different areas (residential, urban, suburban), along with propagation conditions (the number of obstructions and road width, etc.) (Fig. 1) (R11031). kHz-band PLC (power line communication) is one of the most useful communication technologies for apartment buildings. We proposed a new simplified calculation method of transmission loss for multiple branching power lines. We also introduced an approximate equation that enables us to calculate loss easily using typical spreadsheet software and clarified that the equation has enough accuracy (approximation error is less than a few dB) (R11001) (R11015).

2 Demonstration of a New Sensing System Using a Remote Optical Power Supply for a Sensor Network

We have proposed a new multi-point optical sensing system using a remote optical power supply. This system enables facilities monitoring over wide areas such as power transmission lines to use no power equipment at sensing sites (Fig. 2). We developed the prototype system including low-energy optical nodes, and it was confirmed by laboratory experiments that the sensing data from the node located up to 23 km apart can be collected and that sequential data collection from several nodes is possible. Furthermore, it was shown that the system is applicable to remote monitoring for existing on-site ground fault indicators (R11014).

3 Development and Reliability Assessment of IP-based Wide-area and High-speed Control Networks

We have developed communication network technologies that enable the construction of lowcost and high-performance protection and control systems by utilizing the interconnectivity of offthe-shelf IP technology and by implementing the scheme of real-time features and reliability assurance. We have also evaluated the reliability of an IP-based protection system (Table 1) and showed that a redundant system configured with two separate fiber optic and microwave radio networks is required to meet the system reliability requirements (R11032).



Fig. 1: Distance dependency of the propagation path loss with its best-fitting curves for the 950-MHz band and "concentrator to meter" paths

The propagation path loss can be represented by using the best-fitting curves with propagation path loss exponents (n) in terms of the number of obstructions (OB) and road width (RW).



Fig. 2: Multi-point optical sensing system using a remote optical power supply (example for power transmission facilities monitoring)

Driving power for optical nodes is remotely supplied by a laser diode (LD) at a monitoring station, and no power equipment is necessary at sensing sites. In a monitoring station, a signal light to control the optical nodes is transmitted, and a return light modulated by sensor information is received.



Fig. 3: Results of a reliability assessment for IP-based protection systems

Since two separate fiber optic networks are hard to construct, the number of applicable repeater stations and the endto-end transmission path length are restricted. When one network is configured with a microwave radio, they meet the requirement since simultaneous failure occurs less. Project Research - Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power Evaluation of the Feasibility of Demand Response Suitable for Japan

Background and Objective

The "Demand Response (DR) Program," which utilizes Energy Management Systems (EMS), and its technology development is in progress, has been operated recently in the U.S. The DR program also gathers public attention in Japan, on account of the power supply shortage caused by the Great East Japan Earthquake in the short term and of the secure operation of a utility grid and maintaining appropriate power quality in the medium and long term, which has been performed by the supply side exclusively. In this project, we analyze and assess the feasibility of the DR program, which is suitable for demandsupply conditions in Japan, through the analyses of acceptability or cost-benefit for electric utilities of a new DR application, such as the secure operation of a utility grid, the efficient use of idle batteries, or load creation when a solar PV is to be introduced on a large scale, along with peak-shaving.

Main results

A Study on the Possibility of the Implementation of DR for BEMS-equipped Buildings*

We explored the possible and effective peakcutting DR control strategies of air conditioning and lighting systems in an actual office building and a shopping center equipped with a Building Energy Management System (BEMS) based on a combination of building energy simulation analysis and on interviews with building facility managers. Each control strategy was evaluated on four-point scales from three different viewpoints: (1) the utility's benefits, (2) the building owner's (DR participants') benefits and disadvantages, and (3) controllability by BEMS. The results show that reducing lights in office working areas and sales areas has significant potential for peak load saving and is the highestrated strategy among all DR control strategies from the three-viewpoint evaluation (Table 1). Although reducing lights was hard to implement before the Great East Japan Earthquake, this seems to have changed to become acceptable to customers.

2 Development of a Load-scheduling Application (OPTLOAD) for Industrial Customers

We developed a load-scheduling application called OPTLOAD for industrial customers, which have several facilities being operated independently of each other (Fig. 1). The OPTLOAD can optimize the operation planning of facilities and can minimize weekly cost consisting of energy charges and labor costs by adjusting each facility's weekly operation schedule, under the customer's peak demand savings and daily task requirement. The OPTLOAD is applicable to industrial customers that can grasp the electric power demand consumed by each facility.

3 Analysis and Trend Observation of the International Standards Regarding Smart Grid in Customer Domains

We observed the trend of the standard development organizations of customer domains in the U.S. and in European countries regarding international standardization, which has serious influence on the spread of DR in Japan. The conventional OpenADR (Open Automated DR) is collected into late-coming Energy Interoperation (EI), which can respond to a wide range of electricity transactions, and the newest OpenADR2.0 will be announced regarding what was reflected as a part of the EI (Fig. 2). Moreover, OpenADE (Open Automatic Data Exchange), which is a standard for thirdparty access of energy-use information and which was introduced in the smart meter system investigative commission of the Ministry of Economy, Trade and Industry, is taken over to the "Green Button," which is a standard for providing energy usage information to third parties.

			1. Viewpoints		2. Viewpoints of the building owner				
			off the utility Benefits		Disadvantages and barriers			3	
Build- ing	Use	DR Measures	Peak cutting rate*1		Constraints of building facilities and software	Constraints of operation	Acceptance toward changes in indoor environments	Controllability by BEMS	Importance*2
Office buildings	Air conditioning	1. Raising preset temperatures in common-use areas (+1°C, +2°C)	+1°C: 0.17% +2°C: 0.32%		0	0	0	0	С
		2. Raising preset temperatures in office working areas (+1°C, +2°C)	+1°C: 0.69% +2°C: 1.35%		0	0	Δ	0	С
		3. Reducing the volume of outdoon air (25, 20, 15m ³ /[hr•person])	25m ³ /[hr•person]: 0.07% 20m ³ /[hr•person]: 0.08% 15m ³ /[hr•person]: 0.10%		0	0	0	0	с
	Lighting	6. Reducing lights in common-use areas (30%off, 50%off)	-30%: 1.44% -50%: 2.39%		0	0	0	0	С
		7. Reducing lights in office working areas (30%off, 50%off)	-30%: 13.31% -50%: 21.75%		0	0	Δ	0	-30%: A -50%: B
		8. Turning off unused IT machines (30%off, 50%off)	-30%: 8.63% -50%: 14.23%		×	×	Δ	×	В
Shopping centers	Air conditioning	 Reducing the volume of outdoor airl (20m³/[hr•person]) 	0.14%		0	0	0	0	С
		 Raising preset temperatures in storeroom (+2°C) 	0.04%		×	×	Δ	×	D
		3. Raising preset temperatures in sales areas, centrally air conditioned (+1°C, +2°C)	+1°C: 0.15% +2°C: 0.36%		0	Δ	Δ	0	с
		4. Raising preset temperatures in sales areas, individually air conditioned (+1°C, +2°C)	+1°C: 0.02% +2°C: 0.09%		×	×	Δ	×	D
		6. Reducing lights in storerooms (30%off, 50%off)	-30%: 0.57% -50%: 0.92%		×	×	Δ	×	D
	Lighting	7. Reducing lights in sales areas, centrally controlled (30%off, 50%off)	-30%: 15.3% -50%: 25.5%		0	0	Δ	0	A
		8. Reducing lights in sales areas, individually controlled (30%off, 50%off)			×	×	Δ	×	В

*1 The peak cutting rate is estimated through the use of the ESUM v5 building energy simulation tool.

*2 A = Most important (high peak cutting rate, little disadvantages and barriers, controllable by BEMS); B = Important (high peak cutting rate, substantial disadvantages and barriers); C = Less important (low peak cutting rate, little disadvantages and barriers); D = Out of consideration (low peak cutting rate, substantial disadvantages and barriers)

Table 1: Assessment of the importance of load-saving DR methods

Source: Kurosaki, et.al. A Study on the Possibility of the Implementation of a Demand Response Program for BEMS-equipped Buildings (No. 2): Results and Problems of Method, Proceedings of the 28th Conference on Energy, Economy, and Environment, Japan Society of Energy and Resources, pp. 165–168, 2012.



Fig. 1: Calculation flow of the OPTLOAD loadscheduling application





PAP (Priority Action Plan):

A form of technology-focused efforts initiated by the Smart Grid Interoperability Panel (SGIP) of the National Institute of Standards and Technology (NIST). PAPs address specific standards-related gaps and issues for which resolution is most urgently needed.

Fig. 2: Relationship between OpenADR and the relative standards

Energy Interoperation (EI) refers to WS-Calendar, Energy Usage, Facility, and EMIX. OpenADR2.0, which is the newest DR standard and which will be released in a few days, has been the standard that refers to a part of the EI and the apparatus certification procedure, etc., with reference to a part of the EI.

Source: Yamaguchi et al. A Role of OpenADE in Customer Services, The Institute of Electrical Engineers of Japan, PFC-12-003, 2012, revised. Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Operation of Trunk Power Systems in a Coordinated Manner with Autonomous Demand Area Power Systems

Background and Objective

In Japan, a high penetration of renewable generations such as photovoltaic (PV) generation and wind power generation is expected in the future. This high penetration may have an impact on power quality. For example, there are concerns that the quality of voltage and frequency will become much more difficult to manage because of the unpredictability and fluctuation of intermittent generation output. Up to now, generating units connected to trunk power systems provide all of the supply and demand-balancing capability, including LFC capacity and reserve capacity, which is essential to maintain power quality. In the future, a high penetration of intermittent generation requires much more reserve capacity because of the forecast error of their output. Also, it is expected that new facilities such as battery energy storage

systems (BESSs) will be installed in power networks, including those in the demand side. These facilities potentially have a capability that contributes to supply and demand power balancing. Therefore, the utilization of facilities such as BESSs as resources of reserve capacity can be an alternative for effective power balancing in future power systems.

In this project, the utilization of non-generation resources such as BESSs for the compensation of PV generation output forecast errors is considered (Fig. 1). An evaluation method is developed to show how the operation of generating units can be improved by such a utilization to contribute to the development of a cost-effective scheme of resource utilization.

Main results

Evaluation of the Effect of Reserve Capacity by Non-generation Resources

An evaluation method is developed to assess the effect of the utilization of non-generation resources to compensate for PV generation output forecast error. The method uses a supply and demand simulation method and evaluates how the reserve capacity required for generating units can be reduced and, consequently, how the capacity factor of those units can be improved through the utilization of non-generation resources. In this research, non-generation resources are assumed to compensate for PV output forecast errors exceeding a specified level. The main features of the developed method are as follows: 1) The developed method can clarify the relation between the capacity of nongeneration resources utilized (kW, kWh) and the improvement of the capacity factor of generating units. This is useful in finding out how effective the utilization of non-generation resources is.

2) The developed method evaluates the operational capacity factor of generating units, i.e., the ratio of average output in operating hours to the rated capacity. This means that the method can focus on the effect on the operation of generating units.

Numerical Example Using the Developed Method

As a numerical example using the proposed method, an assessment of the effect of reserve capacity by non-generation resources is made assuming a holiday in May (Table 1 and Fig. 2). The measured data of solar radiation at the Akagi testing center and the assumptions of a smoothing effect are used to estimate PV generation output in this example. Also, assumptions are made regarding the PV generation output forecast error. Under these assumptions, the results show that a relatively small amount of non-generation resources can improve the capacity factor of generating units, when PV output forecast error is large.


Fig. 1: Utilization of power-balancing resources under a high penetration of intermittent generations

Table 1: Assumptions in a numerical example

Demand	PV generation	PV generation output	Hourly PV generations output forecast (one day ahead)	
			Fatimation of forecasts	Maximum hourly
	сарасну		Estimation of forecasts	forecast error (capacity-base)
			①Weather-based	
•5,200 MW		 Estimated based on 	 Based on hourly weather 	18.6%
(on a	•2,940 MW	measured data at the	forecasts (no errors assumed)	
holiday in	(53 GW	Akagi testing center	 Small forecast error 	
May, 10 GW	nationwide in	and on the	②Daily output-based	
annual peak	Japan)	assumption of a	 Bell-shaped forecast curve 	31.6%
demand)		smoothing effect	based on daily output (MWh)	
			 Large forecast error 	



- A smaller forecast error and the larger utilization of non-generation resources cause the capacity factor of the generating units and, consequently, the generating efficiency to become higher.
- In this example, even a small capacity of non-generation resources can improve the capacity factor of the generating units, when the PV output forecast error is large, as pointed out by a circle in this figure.

Fig. 2: Relation between the capacity factor of generating units and of the non-generation resources obtained in the numerical example

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Next-generation Electric Power Equipment for Distribution and Transmission Systems

Background and Objective

The aging of electric power equipment is progressing, and in the near future, a huge amount of electric equipment will need to be replaced. On the other hand, since safety and low environmental loading will become important, electrical equipment must be able to deal with these changes and new requirements. Therefore, it is desired that next-generation electrical equipment features high performance for disaster prevention and low environmental loading. In this research, we aim to establish fundamental technology for a superconductive fault current limiter to reduce the constraint factors of power distribution and transmission systems by suppressing short-circuit current, along with low environmental-loading transformers for high public acceptance, in order to propose next-generation technology for replacing aged equipment.

Main results

Development of a Superconducting Fault Current Limiter for Suppressing Fault Current

Bi2223 superconductive thin coating is used for magnetic shielding-type superconducting fault current limiters (SFCLs), which are suitable for application to high-voltage systems, such as high-voltage transmission lines. We found that the critical current density (Jc) can be increased by increasing the pressure of compression molding between sintering treatments during fabrication (Fig. 1). In case of strip shape samples molded with a pressure of 250 MPa, the obtained maximum Jc was 6,000 A/cm², which is close to the practical value. ϕ 450-mm large cylinders (Fig. 2), which will be used for 6 kV- and 60 kV-class SFCLs were molded with a pressure of 150 MPa, which is the maximum available pressure for presently used cold isostatic pressing (CIP) machines, and the obtained maximum Jc was 2,400 A/cm². The Jc was lower than the strip shape sample because of low CIP pressure. Also, we proposed a method to increase threshold energy for the destruction of superconductive coating by Joule heating. In case of strip shape samples, the threshold destruction energy was increased by 2-3 times when compression pressure is 2 MPa (Fig. 3).

Development of Gas/Solid Hybrid Insulation Bus Technology Without SF6 Gas

Gas insulation electric equipment must be properly managed to suppress gas leakage into the atmosphere, as SF₆ gas, which has high global warming potential, is used in gas insulation equipment. CRIEPI proposed a gas/ solid hybrid electrical insulation method using natural gas such as CO₂ or N₂ instead of SF₆ and a conductor thickly coated by solid insulation material. In a hybrid gas insulation bus, the joint of coated conductors is the weak point of electrical insulation. Therefore, we proposed a joint structure with an electric field shield as shown in Fig. 4. It is expected that the crosssection of a bus joint can be reduced to 1.1 times that of a conventional SF₆ gas-insulated bus, on the basis of experimental results and electric field analysis (H11001). We designed and made a prototype model of a 300 kV-class hybrid gas insulated bus (Fig. 5).

3 Development of Elemental Technology for an All-solid Insulated Transformer

The all-solid-insulated transformer is very attractive because of its high safety, compactness, and low environmental loading, owing to its oil-free insulation. So far, CRIEPI made a small outer-layer grounded allsolid-insulated transfer model with an easily detachable, all-solid compact connector, known as the "hyper connector." We are evaluating the performance of this small model to accumulate data regarding insulation and thermal properties, which is necessary for designing a 60 kV-class all-solid transformer.



Fig. 1: CIP-pressure dependence of the critical current density

Transition of the critical current density of short samples with increasing CIP pressure between the sintering treatments at the same sintering conditions (temperature and number of sintering treatments)



Fig. 2: Prototype large cylinder of ϕ 450 mm in diameter



We measured the applied energy until when short samples are destroyed by Joule heating during over-current more than the critical current density.



Fig. 4: Hybrid gas-insulated bus and the joint part structure

By coating a high-voltage conductor with a thick solid insulator (up to 10 mm), the maximum electric field in the gas is reduced; therefore, compact equipment is available using natural gas such as CO₂. By using electric field shielding inside a supporting spacer, the deterioration of the electric insulation performance of the jointing and supporting part can be reduced.



300 kV/4,000 A Bus model for single phase

Cross section: φ140/400 mm coaxial (coating thickness of 10 mm)
Length (including edge electrode): Up to 3 m (with three conductor-supporting spacers and edges)

Fig. 5: Container including a prototype 300 kV-class gas/solid hybrid insulated bus model

The sizes of a prototype 300 kV-class gas/solid hybrid insulated bus model were derived from electric field design on the basis of insulation breakdown characteristics of the structure of jointing and supporting, and thermal dissipation characteristics of solid insulation coating and gas.

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Design Support for Electric Kitchens

Background and Objective

Commercial electric kitchens are becoming widespread, as they feature a lack of exhaust combustion gas, they emit less radiant heat, and they are highly energy efficient. They can also contribute to energy-saving and reduction in indoor thermal environmental impact. However, the effects of energy-saving and size reduction on air conditioning systems for kitchens are not actually brought out enough, as the required ventilation air volume is determined in conformity to gasfired kitchens. In this project, we develop a design support tool for commercial kitchens and element technologies for efficient ventilation and the accurate measurement thereof.

Main results

Development of a Test Facility for Ventilation Performance and the Measurement of the Ventilation Efficiency of Commercial Electric Kitchens

In order to precisely measure ventilation efficiency (ratio of the oil mist generated from cooking appliances to that collected from an exhaust hood), we developed a test facility to control ventilation air volume accurately (Fig. 1). We also developed a tracer oil mist generator that imitated the particle size distribution of oil mist generated from griddles, fryers, and steam convection ovens. By using the facility, we obtained results showing no descent in ventilation efficiency by cutting down ventilation air volume to 70% of the current standard value under calm conditions (R11005, V11024). In order to evaluate the influence of air turbulence generated by a cook's motion on ventilation efficiency, we analyzed a cook's motion in an actual kitchen in detail and modeled such. We found out that the descent in ventilation efficiency caused by air turbulence generated from a board imitating a cook's motion (a turbulence generator) was only slight (Fig. 2) (R11016, R11023).

2 Measurement of the Energy Consumption and Thermal Environment of an Actual Commercial Kitchen (Comparison of Before and After Electrification)

We carried out a long-term measurement of consumption of electricity, gas, and water, along with the indoor thermal environment of an actual commercial kitchen, before and after electrification (Fig. 3) (R11006).

3 Examination of the Design Standard for Commercial Kitchen Ventilation in VDI

We examined the design standard for commercial kitchen ventilation in VDI, which is widely applied to Europe, through bibliographical surveys. The VDI standard has features that allow transient air leakage from the exhaust hood and that collect such gradually, therefore sufficiently suppressing the required ventilation air volume. This enables us to achieve energysavings in air conditioning and to reduce the size of air conditioning systems for kitchens (R11004).



Fig. 1: Outline of the test facility for commercial kitchen ventilation

The test facility enables us to accurately control ventilation air volume, supply air temperature, and relative humidity.



*2 Average velocity of cooks who cross in front of cooking appliances

Fig. 2: Relationship between the ventilation efficiency of the hood and the motion frequency of the turbulence generator

There is no remarkable reduction in ventilation efficiency at the velocity and the frequency of an actual cook's motion in front of cooking appliances.



Fig. 3: Temperature in the kitchen in the summer

The gaps in temperature in the kitchen have decreased due to electrification repair work. Excessive rises in temperature are not observed even near the cooking appliances. The thermal environment in the kitchen has improved.

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

High-efficiency Heat Pumps

Background and Objective

Heat pumps, such as air conditioners or water heaters, etc., are widely used to promote energy conservation and to reduce carbon emissions. The development of more efficient heat pumps with low GWP (Global Warming Potential) refrigerants and their expansion to new areas of application is needed.

CRIEPI embarked on basic research into CO_2 heat pumps in 1995 and finally commercialized a

CO₂ heat pump water heater for residential use in 2001, with the pet name "Eco-cute," in conjunction with Tokyo Electric Power Company and DENSO Corporation.

In this project, we aim to evaluate the performance of the next-generation Eco-cute and to develop a more efficient version. We also assess the potential for heat pumps used in commercial and industrial sectors with low GWP refrigerants.

Main results

Performance Evaluation of Various Types of Eco-cute Versions

We have evaluated the performance of various types of Eco-cute version, such as the conventional type, small-sized type, and cold-area type utilizing heat pump performance test facilities. In addition, in FY2011, we evaluated the system COP (daily hot water and room heating demand/daily power consumption) of the multi-function type, which had a room-heating function. In this type, the quantity and balance of hot water demand and room heating demand affect the system COP. Thus, first, the daily power consumption

was divided into standby power consumption and heat pump unit power consumption. Further, heat pump unit power consumption was divided into rated power consumption, power consumption caused by high outlet water temperature, and power consumption caused by high inlet water temperature. We proposed this evaluation method (Fig. 1) and confirmed that the quantitative analysis of the system COP was possible by this method.

2 Development of a CO₂ Heat Pump for Central Heating Systems

A central heating system is widespread in cold climates. Such a system heats all rooms of a house, usually by utilizing hot water. Hokkaido Electric Power Company, SANDEN Corporation, and CRIEPI jointly developed an air heat-source CO₂ heat pump for a central heating system (Fig. 2). The developed heat pump, due to the modified two-stage cascade heating cycle,* can produce a high temperature of 70° C in the hot water even in the condition of an ambient air temperature of -20° C.

B Development of Small Heat Pumps for Industrial Drying

In industrial processes such as the process of drying parts after washing with water, hot air heated by an electric heater is frequently used. Thus, equipment that utilizes energy-saving heat pump technology is highly required. We have been developing a CO₂ heat pump air heater since FY2010 based on the technology acquired through the development of Eco-cute. In FY2011, bearing in mind commercialization, a prototype that can be operated using automatic control

was designed, fabricated, and tested utilizing heat pump performance test facilities. Under the automatic control operation, a COP of about 3 and a heat output of 3 kW were achieved under the condition that the inlet and outlet air temperatures were 25°C and 100°C, respectively, and in which the heat source water temperature was 30°C (Fig. 3). This may reduce power consumption to about 1/3 compared with the conventional process (M11005).

*High-temperature side-heat pump cycle and low-temperature side-heat pump cycle are connected in series via a heat exchanger. This cycle is adopted to make a high temperature from low-temperature ambient air or to make a very low temperature.



Fig. 1: Proposal of the evaluation method for Eco-cute

The figure shows schematically the increase of heat pump unit power consumption from start to finish for water heating (thermal storage). The heat pump unit power consumption at the rated inlet water temperature and the low outlet water temperature is the smallest (*E1*, rated power consumption). However, in actual operation, the outlet water temperature becomes high to ensure the storage of heat needed. Further, due to the influence of hot water remaining in the hot water tank, the actual inlet water temperature becomes high. Because of these, heat pump unit power consumption is increased ($\triangle E1$, $\triangle E2$). A quantitative analysis of the system COP can be done by evaluating each of these effects. The proposed evaluation method can also be applied to various types of Eco-cute.





Fig. 2: Prototype of the CO₂ heat pump for a central heating system tested at heat pump performance test facilities

Size: 828 (width) \times 283 (depth) \times 1,280 (height) mm The prototype was tested utilizing the test facilities. We have developed a method of defrost control.

Fig. 3: Test results of the prototype for a small heat pump for industrial drying

In Figure 3, the horizontal axis shows the outlet air temperature and the vertical axis shows heat output, power consumption, and COP. Even if a high temperature of 100°C hot air was produced, a COP of about 3 was obtained (red circle in the figure).

2 Principal Research Results

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Low-loss Power Semiconductor

Background and Objective

The development of high-efficiency and compact semiconductor power conversion equipment is a common technical issue regarding the power control of plug-in hybrid or electric cars, IH cooking heaters, heat pump hot-water systems, and power transmission/distribution systems. The wide range practical use of SiC power semiconductor devices, which can realize loss reduction and higher withstanding voltage compared to conventional Si power devices, is expected to contribute toward solving the common issues.

This project aims at the development of technologies for the production of high-quality SiC crystals and the performance improvement of high-voltage devices.

Main results

Optimization of the Defect Reduction Process

Thick and high-purity single-crystal SiC films (epilayers) with a long carrier lifetime are essential to realize high-voltage and low-loss SiC switching devices (SiC-IGBT^{*1}). We obtained thick SiC epilayers (up to 140 μ m) and a low nitrogen doping concentration (3×10¹⁴ cm⁻³) corresponding to a withstanding voltage of 13 kV, which can be adapted to high-voltage power systems, and applied the original defect reduction process named "C-ion implantation and annealing process"^{1,2} to the epilayer with

different conditions. This post-growth process eliminates carbon vacancy-type point defects and improves carrier lifetimes, and is proven to be able to eliminate defects below the detection limit throughout the volume of the epilayers more than 100 μ m from the surface by adjusting the annealing temperature to 1600°C. As the result, we succeeded in enhancing the carrier lifetimes from 2 μ s (before the process) to 12.8 μ s (after the process) in excess of the requirement values of 5-10 μ s for the 13 kV devices (Fig. 1).

2 Development of Defect Conversion Techniques

We clarified that the dislocations (basal plane dislocations: BPDs) causing the degradation of the current conduction performance of SiC bipolar devices such as IGBT^{*1} are reduced by high-temperature annealing in Ar ambience. This is a new method to convert BPDs to other-type dislocations (threading edge dislocations: TEDs) having no negative impact on the degradation, and we confirmed the conversion of the tip of BPDs to TEDs by synchrotron

X-ray topography (Fig. 2)³. We also developed a three-dimensional topography technique using a synchrotron X-ray micro beam as a new method to observe dislocations in SiC epilayers to make it possible to optimize the dislocation conversion process and to clarify the conversion mechanism. We succeeded in obtaining three-dimensional images of the BPD-TED conversion points (Fig. 3).

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

*1 IGBT: Insulated gate bipolar transistor

Related Patent Submissions and Papers

- 1 Patent submission 2008-53667, Methods to improve the quality of SiC crystals and SiC devices 2 L. Storasta and H. Tsuchida, Applied Physics Letters 90, 062116 (2007)
- 3 Patent submission 2011-118419, Production methods of SiC substrates and SiC wafers and SiC semiconductor devices



Fig. 1: Changes in the carrier lifetimes of SiC epilayers before and after the carbon ion implantation and annealing process with different annealing temperatures

Carrier lifetimes express the decay times of excess electrons and holes to become the thermal equilibrium, and a longer carrier lifetime achieves low-loss current conduction.



Fig. 2: Conversion of BPDs to TEDs by high-temperature annealing

Synchrotron X-ray topography images of a SiC epilayer (a) before and (b) after 1800°C annealing, showing the conversion of the BPD tips to TEDs; (c) schematic drawing of BPD-TED conversion by high-temperature annealing.



Fig. 3: Three-dimensional synchrotron X-ray topography image taken for a position of BPD-TED conversion

The three-dimensional observation of a BPD-TED conversion is possible by making a side-view of a synchrotron X-ray topography image.

Project Research - Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Low-loss Compact Inverter Applied Equipment

Background and Objective

Innovation in the power electronics technology can play an important role in realizing a low-carbon society and stable electric power supply, including the introduction of renewable energy sources. As a core of such innovation, the development of electric equipment that utilize SiC semiconductor devices (SiC devices) can achieve low power loss, small size, and high control performance.

Another possible innovation is the improvement of the stability of the electric power supply system by developing and applying a novel highvoltage DC transmission system for enforcing grid interconnection and for the increase of renewable energy sources, which have recently gained prominent attention.

In this project, we establish the simulation and control technologies of power electronics systems. Based on the technologies, we develop SiC deviceapplied equipment and novel high-voltage DC transmission systems, which can meet recent needs.

Main results

Development of an Existing-SiC-device-applied STATCOM for Distribution Systems

We have developed a prototype for a 6.6-kV transformerless STATCOM^{*1} by combining existing SiC devices and Si devices (Fig. 1). The prototype is based on the multi-voltage cascade converter^{*2} and realizes direct high-voltage output of 6.6 kV. Development of a novel pulse control method realizes a small AC filter and small power loss. A series of basic performance verification tests were executed by the prototype. Reactive power control and DC voltage balancing control among the cells were

verified to have enough performance for actual use in steady-state operations. The development has been implemented under the cooperative research with Toshiba Corporation.

This result can be applicable to develop demonstrative equipment implemented in a small container for pole-top mounting by verifying the control performance during faults and by optimizing its design with utilizing the simulation models developed in our laboratory (R11028).

Proposal of a Novel High-voltage DC Transmission System

DC line faults are usually cleared using AC circuit breakers in conventional voltage source converters based high voltage DC transmission (HVDC) systems because the fault current continues to flow after halting the converter. As a result, it takes time to resume power transmission, and such interval is a problem when realizing quick recovery from a lightning failure in an HVDC system having overhead transmission lines. We propose two methods to solve this problem. One method is to use a full-bridge cell MMC^{*3} and suppress the DC

fault current using the converter's control (R11021). The other method is to remove the fault section by using high-speed solid-state DC circuit breakers'⁴ (R11018) (Fig. 2). These methods can realize the quick recovery of the power transmission in a DC line fault. The first method can be quickly put into practical use by utilizing existing control and protection technology for line-commutated current-source converters. The second method is effective for future multi-terminal DC grids because it can remove only the fault section.

^{*1} STATic synchronous COMpensator: Reactive power compensation equipment using a voltage source converter

 ^{*2} A circuit configuration for a multilevel converter: It has multiple single-phase inverter modules of which the DC voltage is different. They are connected in series and operate as a high-power converter.
 *3 A modular multilevel converter (MMC) is a converter consisting of cells (modules) having identical voltage rating among them. A full bridge cell

^{*3} A modular multilevel converter (MMC) is a converter consisting of cells (modules) having identical voltage rating among them. A full bridge cell MMC consists of series-connected several single-phase inverter modules.

^{*4} Includes not only pure solid-state breakers, but also hybrid breakers of high-speed mechanical switches and solid-state switches.



Fig. 1: Prototype of the transformerless STATCOM consisting of existing SiC devices and Si devices (rated at 6.6 kV in voltage and 100 kVA in power)

A full scale STATCOM prototype was developed. It consists of 1.2 kV SiC-JFET devices that have excellent switching performance and 4.5 kV Si-IGBT devices that feature low conduction loss. The operation of the prototype was confirmed by a series of verification tests on basic performance.



Fig. 2: A circuit configuration of the proposed voltage source converter-based high-voltage DC transmission systems using DC circuit breakers.

Several switching devices are able to be connected in series by paralleling a circuit for maintaining equal voltage-sharing among the devices [b] to the semiconductor devices [a] to realize the high blocking voltage of the DC circuit breakers. A freewheeling diode [c] can bypass the fault current and slowly reduce the fault current to suppress the surge voltage arising from the current blocking.

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Acceleration of Electrification with Electric Vehicles and Secondary Battery Systems

Background and Objective

As measures against global warming, the introduction of a low-carbon electric power supply and the promotion of energy conservation are important. Moreover, the electrification of the public welfare and transportation sections, which have been increasing in energy consumption carbon dioxide emissions, is effective for energy conservation.

In this project, a hybrid energy storage battery system with a heat pump hot water supply system for residences is proposed toward electrification for public welfare services with the utilization of secondary battery technologies. Moreover, in transportation, while the policy for the acceleration of the popularization of electric vehicles (EV) and for the preparation of a charging infrastructure is shown, charging technologies should be developed with safe and high performance.

Main results

Hybrid Energy Storage Battery System with a Heat Pump Hot Water Supply System for Residences

We proposed an optimized control method for residential hybrid energy storage battery systems with a heat pump hot water supply system, which takes into consideration not only technical factors such as outside temperature, energy loss due to the start-stop of the heat pump and the radiation of heat from the hot water tank, but also time-of-day electricity fees. Through our new control method, heat storage management using a heat pump depends on the residual heat in the hot water tank every hour instead of the conventional daily total heat mass usage, such that the efficiency of operation can be enhanced, due to the elimination of the need for further energy charges.

2 Acceleration of the Popularization of EVs

(1) Advancement of analysis on the effect of a charging infrastructure by traffic simulator

The shorter drive range of an EV compared to a gasoline vehicle is the critical disadvantage for wide diffusion of EV in the market. To overcome this disadvantage, it is important to comprehend the drive range of EVs in various operation conditions, to construct an infrastructure network, and to find suitable usage for EVs. Here, a Japanese nationwide database of charging infrastructures has been constructed, and that database contains information such the number of installations per prefecture, location, business hour, and the operating company of the charging infrastructure. Using the database, we have made clear the effect of the installation number and business hour of the charging stations on the number of EVs running out of electricity by using a traffic simulator developed at CRIEPI.

(2) Development of an EV driving mileage simulation code

Simulation codes for the EVs currently on sale were developed from EV driving data (Fig. 1). This simulation considered both the regeneration of energy from braking and altitude changes on driving course. This simulation code can evaluate the changes of driving mileage against the battery capacity mounted on EVs (Fig. 2)(M11023).

(3) Development of a bi-directional inductive charging technology

A wireless vehicle-to-home (V2H) module, through the use of a bi-directional inductive power transfer setup, was developed. We tried to connect the module directly to a conventional power conditioner and demonstrated the operation of a stand-alone AC power supply until 1.2 kW with an efficiency of 92% was successfully achieved (Fig. 3)(H11028).

(4) Potential penetration of EVs for domestic use

We identified the potential penetration rates of EVs considering their demerits compared to gasoline-powered vehicles, such as shorter mileage, higher initial cost, and the installation of a charging infrastructure by analyzing data collected through a Web-based questionnaire survey. Even if the initial EV price is reduced to that of a gasoline-powered vehicle and if the mileage per charge is extended to 300 km, the rate is only 2.3%. In order to promote EVs, it is important to extend the mileage, lower the price, and enhance driver understanding regarding the installation of chargers at home (Y11032). In addition, we found that the success of EV adoption with vehicle-to-home power systems is reliant on the price decline of such systems (Y11021).



Fig. 1: Comparison of driving mileage calculated by the simulation code and measured during EV driving

Simulation code can predict in $\pm 10\%$ of accuracy electric mileage except for extreme traffic congestion (No. 1-1) and mountain slope (No. 3-2). *D mode: Usual mode, B mode: high energy regeneration mode



Fig. 2: Evaluation of driving mileage against the battery capacity mounted on EVs

The possibility of the cruising range distance extension in consideration of the increase in weight of vehicle was examined by making battery capacity into a parameter supposing the improvement in performance of EV. (Calculation case was No. 2-3 in Fig. 1)





(R) Spiral coils assembled in an inductive power transfer setup

(L) Block diagram of an experimental setup

Fig. 3: Wireless vehicle-to-home module connected to a conventional power conditioner

A wireless vehicle-to-home (V2H) module, through the use of a bi-directional inductive power transfer setup, was developed. We attempted to connect the module directly to a conventional power conditioner and successfully demonstrated the operation of a stand-alone AC power supply. This technique adds the advantage of mobile storage to the EV without weight increase.

Project Research - Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Project Research — Development of a Supply/Demand Infrastructure for Next-generation Electric Power

Lithium Secondary Batteries with Reliable Safety

Background and Objective

Dispersed battery energy storage systems are expected to be used in residential applications (kWh-class) and on-site leveling operations of renewable power generation (MWh-class). Although lithium secondary batteries exhibit high energy density, energy efficiency, and rate capability, the determination of long duration life and reliable safety in large batteries is needed to perform installation on a system level. This subject shows the direction at which to build up lithium-ion battery performance during long-life operation using non-destructive and simple analysis techniques. In addition, this subject proposes the improvement of battery performance of all-solid-state lithiumion batteries using solid polymer electrolyte. The proposed battery is expected to improve safety, cost performance, and simple large battery production compared to the conventional lithium-ion batteries with flammable liquid electrolyte.

Main results

Lithium-ion Battery Evaluation: Development of Performance Evaluation Using Actual Operation Patterns

Although the life evaluation of lithiumion batteries is generally determined using constant current charge-discharge operation, actual operation includes complicated charge/ discharge patterns. We thus compared the capacity degradation between simulated leveling cycle patterns of photovoltaic (PV) power generation (real PV cycle operation) and constant current cycle operations. We assume that capacity degradation can separate cycle operation factors and duration factors. Further, we found that the extracted cycle degradation ratio was independent of operation patterns, which suggested that we could evaluate the battery degradation in actual operation by using a simple constant current operation protocol (Fig. 1) (Q11015).

2 Lithium-ion Battery Evaluation: Development of Degradation Component Evaluation

The understanding of battery performance degradation from basic battery components is important for precise battery life evaluation. We proposed to estimate the cathode component ratio from the derivative analysis of the voltage profile in (LiMn2O4: LMO)/(LiNi1/3Mn1/3C01/3O2:

NMC) mixed cathode materials without disassembling the cell. This procedure could also apply to the estimation of the degradation factor in the mixed cathode materials (Fig. 2) (Q11022).

Development of an All-solid-state Lithium-ion Battery: Achievement of Comparable Long Life to that of Commercialized Cells

All-solid-state lithium-ion batteries using solid polymer electrolyte have compatibility with the cathode and anode materials that were already used in conventional lithium-ion batteries. In addition, the proposed battery is expected to reduce the assembly cost and can produce large formats without difficulty. These features are superior to those of other all-solid-state batteries. We introduced an antioxidant into the electrolyte to reduce the side reaction between 4-V class cathode material (NMC) and solid polymer electrolyte with a suitable choice of lithium salts, and established 1,500-cycle operation using a lithium metal anode (Fig. 3) (Q11017) (Q11020). Furthermore, we assembled an allsolid-state lithium-ion battery using aluminum laminate housing, graphite anode, and NMC, and exhibited 500-cycle reversible operation (Fig. 4) (Q11014).



Fig. 1: Relative capacity retention of batteries in an actual PV cycle and constant cycle operation

Capacity retentions of the actual PV pattern cycle (\diamondsuit) , constant current cycle (\bigcirc) , and corrected capacity retentions without duration degradation factor (\diamondsuit : real PV pattern cycle, \boxdot : constant current cycle); the corrected results exhibited similar degradation trends, which suggested that we could estimate the battery capacity degradation of actual operation by using a simple constant current condition.



Fig. 2: Comparison of relative capacity in a degradated mixed cathode

Voltage profiles (cell voltage response to electrode capacity) exhibit each unique characters such that each electrode capacity ratio obtained from the derivative analysis (•) showed good corresponsive trends to those obtained from the loading weight ratio.



Fig. 3: Cycle performance of 4 V-class cathodes and lithium metal anodes

An optimized cell with a 4 V-class cathode, solid polymer electrolyte, and lithium metal exhibited the longest operation of 1,500 cycles.

Operation temperature: 60°C, capacity retention at an eight-hour rate



Fig. 4: Cycle performance of an all-solid-state lithium-ion battery using a 4 V-class cathode, solid polymer electrolyte, and graphite anode

An all-solid-state lithium-ion battery with electrode materials compatible with those of conventional lithiumion batteries showed good cycle performance comparable to that of commercialized lithium-ion batteries.

Operation temperature: $60^\circ\mathrm{C}\text{,}$ capacity retention at an eight-hour rate

Socio-economic Research Center

Brief Overview

The Socio-economic Research Center, through proper understanding of the changes of the business environment and of the society surrounding the electric power industry, endeavors to present solutions to various utility management issues in the socioeconomic circumstances and energy and environmental issues, and thereby to contribute to the electric utilities' business planning as well as to the energy and environment policy developments.

Achievements by Research Theme

Utility Management and Policy

Via quantitative and multi-dimensional analyses of possible impacts of changes in the business environment and social structure on the electric utility industry, we strive to propose desirable institutional designs, as well as directions for electric utility industry management.

- By analyzing the cost structures of nine electric utility companies in Japan, we found that: (1) the economies of scale have shrunk in the power generation sector since 2004, while they still prevail in the transmission and distribution sector, though they have almost reached to their optimal levels, and (2) the economies of vertical integration, expressed as virtual cost savings from the imaginary case where generation and transmission are disintegrated, are evaluated as 19–29% of the current cost basis in average across the nine utility companies (Fig. 1) (Y11009).
- We established a methodology to estimate the LNG consumption savings gained by connecting two LNG terminals operated by an electric power company. Based on past records, the savings could be as much as 3.4% (Y11007).
- We developed an optimization model to determine thermal generators' operation patterns under multi-area cooperation, taking fluctuation of wind power outputs, operational constraints of fossilfired power generation and mechanisms to secure operating reserves into account. The model proves itself effective to evaluate the "value of operating reserves" in terms of the fossil fuel cost additions needed for securing reserve capacity (Y11025).

Through a series of psychological experiments to analyze hindrances for accurate transfer of riskrelated information, we identified a cyclical process where a false report by the information provider evokes the receiver's self-protective (risk-aversive) attitude and distrust to the provider, which then leads to further false reporting (Y11011).

Economic and Social Systems

We aim to clarify the impacts of various policy instruments for reconstruction after the 2011 Great East Japan Earthquake on the macro and regional economy in Japan. We also investigate interests among stakeholders in the policymaking process for disaster prevention in wider-range administration bodies and draw meaningful implications toward policy decisions.

- A questionnaire survey was given to companies in Miyagi and Iwate prefectures after the 2011 Great East Japan Earthquake. The surveys found that, in the regions that were not affected by the tsunami, the production capacities of the manufacturing sector had recovered to 90–100% of the pre-quake level within six months after the earthquake. It also found that the majority of the companies have intentions of continuing their business without changing locations, and relocations outside the Tohoku region are limited (Y11022).
- We examined the effects of population density and market access on industrial productive efficiency in the Japanese regional economy. As a result, we clarified that "agglomeration economies" had a positive effect on the productive efficiency of some

individual manufacturing sectors and that this result was robust (Y11004).

- Interviews to the stakeholders in the administrative sector and industrial sector in the Kansai and Tohoku regions point to the fact that one of the key drivers to promote wide-range cooperation in the Tohoku region during the reconstruction period will be the leadership of the industrial sector to coordinate interests among sectors (Y11035).
- We analyzed the stochastic process of both the national and regional business cycles of Japan. From our empirical results, it was found that the amplitude of the regional business cycles was enlarged after the Great East Japan Earthquake in all regions, excluding Hokkaido, Kansai, and Kyushu (Y11026).



Energy Technology Policy

Toward realization of a low-carbon society and for ensuring energy security, we aim to develop various methods for analyzing energy supply and utilizing technologies, and investigate various energy policies including nuclear utilization.

- We developed a new integrated assessment model, called the BET (Basic Energy Systems, Economy, Environment, and End-use Technology) model, which includes not only global energy systems, economic growth, and climate science but also end-use technologies. A series of model runs revealed that the end-use technologies including electrification are an important mitigation measure for climate change (Y11005).
- Through a detailed analysis of the legal problems and other factors that the Fukushima Daiichi nuclear

disaster raised, we proposed rational directionality and two concrete options regarding the Japanese nuclear third party liability system in order to alleviate the problems (Y11024).

As one of the design and evaluation methods for physical protection systems to protect nuclear facilities, we surveyed the features of the performance-based method studied by the Sandia National Laboratories of the United States and clarified the problems regarding if a similar method was introduced to Japan (Y11030).



Fig. 1: Vertical economies and scale economies of electric power companies

The bar graph indicates the cost-saving effects obtained from vertical integration in an average of nine general electric utilities. The cost-saving effects represent an upward trend in recent years. Such a trend implies that cooperative operation and investment planning between the generation and transmission/distribution sectors are gaining importance for utility management.

System Engineering Research Laboratory

Brief Overview

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

Achievements by Research Theme

Electric Power Systems

We clarify the effect of the large penetration of distributed generations on power system stability in terms of voltage deviation and power oscillation at the system fault condition. The development of distributed generation models is also an important task to conduct such power system stability analyses. In addition, we develop a support tool to coordinate protection relays under circumstances of increased complexity with a large penetration of distributed generations.

- Through a power system simulator experiment, we discovered unstable phenomena due to large amount of PV (photovoltaic) installations, such that system voltage did not recover after a system fault and that power oscillation increased with multiple oscillatory modes. PV models for stability analysis incorporating principal control and protection functions to analyze PV dynamics were verified through a comparison with experimental results.
- We improved the assessment method taking care not to overlook the malfunction of protection relay coordination in the condition of distributed generation installation and power flow change. This enabled almost every distribution system relay for short circuit protection and grounding fault protection to evaluate the relay coordination (R10007).

Customer Systems

We develop element technology for supporting the acceleration of energy-saving. We also clarify the effect of harmonic current flowing from customers connecting to high-voltage (6.6 kV) distribution lines on the suppression of the increase in voltage distortion of the distribution line.

- We developed a heat source characteristic model through which the heating performance of homeuse air conditioners with defrost operation can be calculated simply by using an open technical document. We also verified the accuracy of the developed model by experimentation. The results led to the possibility of the high-accuracy estimation of air conditioner consumption power under various operating conditions, including defrost operation (R11017).
- We clarified that the harmonic voltage of a distribution line was due to harmonic current flowing from single-phase loads, while harmonic current flowing from three-phase loads restrained harmonic voltage (Fig. 1). We also clarified that the addition of series-inductive reactance to a capacitor installed at a high-voltage-using customer for reactive power compensation was an effective measure toward suppressing harmonic voltage (R11003) (R11009).

Communications Systems

As fundamental technologies of future communications networks for power utilities, we develop disaster countermeasure technologies, communication media technologies for facility maintenance work, security technologies for SCADA systems, and others.

- In order for the disaster tolerance of access optical fiber networks (PON) to be improved, we have proposed a highly dependable PON transmission system. An optical switch is installed at the shared transmission line of the PON system to connect with a neighboring shared line as a bypass route during communication failures (R11034).
- To improve the fault tolerance of IP networks, we proposed a faster route reconstruction method. While the existing routing protocol requires a long time to detect network failure by sending the hello packets periodically, our proposed method achieves a faster detection time by monitoring user IP packet flows on the network at any time (R11022).



Mathematical Informatics

To realize accurate diagnosis in electric power equipment maintenance and inspection, 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.

- To support the restoration operation of power systems, we developed an efficient method to numerate all the restoration operations with the lowest unrestored loads and the minimum number of switching operations, and to classify them into various groups based on a restoration policy using the clustering technique (Fig. 2) (R11020).
- To observe the movements of overhead power lines during severe weather, we developed a new stable video tracking method to detect the targets attached to wires even in low visibility with heavy snow, by narrowing the existing areas of the targets based on the physical constraints and on image processing (R11007).



Daily change of fifth-order harmonic voltage, which is the largest value of all the orders (average of 66 measuring sites): Harmonic voltage tends to decrease in the daytime when loads increase, due to the suppression effect of three-phase load.

Fig. 2: An example of enumerating all the optimal restoration operations

Similar restoration operations are classified into the same groups based on a restoration policy (restoration route, etc.).

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 means of 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 is accepted by society in a positive manner.

Achievements by Research Theme

Nuclear Power Generation Technology

To contribute to the safety/stable operation of existing reactors, nuclear power generation technologies including fuel/core safety assessment technologies, technologies for risk-informed safety analysis, and thermal hydraulics, etc., are established.

- In order to evaluate the irradiation effect on the corrosion resistance and hydrogen absorption of fuel claddings, we investigated the chemical composition of Zircaloy-2 cladding, which is irradiated in a commercial BWR. We succeeded in obtaining elemental concentration in the specimens precisely and observed the precipitates, which improve the corrosion resistance dissolved in a matrix by neutron irradiation (L11021).
- The methodology for analyzing common-cause failures (CCFs) for the probabilistic risk assessment (PRA) of nuclear power plants (NPPs) is established. The process is to evaluate the possibility of CCFs by investigating component failure records and to estimate the CCF model parameters using the evaluation results. With this methodology, the domestic CCF parameters are calculated for the major safety components at Japanese NPPs (L11018).

Advanced Nuclear Fuel Cycle

The elemental and advanced technologies for aqueous reprocessing and the basic technologies for metal fuel cycles are developed aiming at starting the commercial operation of the Rokkasho reprocessing plant and at realizing the followed FBR fuel cycle. In addition, we contribute to the technical development of contaminated-water treatment systems at the Fukushima Daiichi Nuclear Power Station.

- In order to study the chemical reaction system in a glass melter at the reprocessing plant, we tried to visualize the series of chemical reactions in which high-level liquid waste is evaporated to dryness and consequently melted into the glass. The change of the physical property of the glass including noble metals is also studied (for example, viscosity).
- A conceptual design study for a metal fuel cycle facility (having a capacity for four units of 15-GW FBR reactors) is conducted based on the

results obtained during elemental technologies development. It is concluded that adequate, lower fuel cycle costs can be attained compared with the same capacity facility for oxidized fuel (L11009).

By applying the technologies developed for pyro reprocessing, the removal characteristics of Cs by zeolite are studied and the calculation code is also developed in a very short time for operation support. These results contribute to the construction of the contaminated-water treatment system.

Reactor Systems Safety

To reduce uncertainty regarding the safety evaluation of a nuclear reactor including a severe accident, validation data on the two-phase flow that influences core cooling is obtained, the analysis precision of the safety evaluation is improved, and a new analytical model is proposed.

- A three-dimensional bubble-velocity-determination algorism that can obtain validation data for nuclear power plants is developed. This algorism enables the direct measurement of the bubble behaviors and the bubble-velocity differences that are caused by bubble interactions (L11014).
- Three-dimensional flow dynamics in a rod bundle, which simulates a BWR fuel rod bundle, were

measured by a developed void sensor, and this demonstrated the transition boundary of a flow regime (L11011).

A TRACE code was validated against an experimental stability database based on the test facility, which simulates a BWR. The results indicate that the boiling correlation needs to be improved in the code (L11006).

Achievements by Research Theme

Human Factors Research

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

- We found that a High Reliability Organization (HRO), which can properly deal with unexpected events, has both an excellent ability to cope with emergencies and an excellent culture of safety, focusing on preventing human errors and accidents. We also clarified the roles of such a safety culture to build an HRO.
- We improved the method of analyzing human-factor events with emphasis on analyzing the causal factors of rule deviations. This method enables analysts of human-factor events to consider reasonable corrective actions, taking into account the actual conditions of rule deviations within an organization.

Nuclear Power Technology Applications/Innovative System Assessments

Innovative technologies obtained from nuclear power R&D are applied to other industrial fields, and technological assessments on the key technologies of the power system are carried out for the settlement of R&D strategies for future nuclear power systems.

The present technological gap to be made up for by fusion energy development was evaluated by using the Technological Readiness Level (TRL) method developed by NASA, and the fusion power control method by changing the density ratio of a fuel particle (hydrogen) and a fusion-product (helium) was also proposed.



Cs adsorption column

Fig. 1: Small zeolite column test equipment for the Cs adsorption apparatus at the Fukushima Daiichi Nuclear Power Station (left) and the calculated analysis using the developed code in CRIEPI (right)

The adsorption performance of KURION media was evaluated using the small-column test. The calculation code developed in CRIEPI accurately evaluated the actual Cs adsorption system. These results have been used to support the determination of an optimized operation schedule and have contributed to minimizing radioactive waste and the exposure of workers to radiation at the Fukushima Nuclear Power Station.

Civil Engineering Research Laboratory

Brief Overview

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

Achievements by Research Theme

Geosphere Science

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

- Based on a worldwide compilation of the magmatic properties of erupted magma, we showed an evidence-based estimation of the upper-limit viscosity of eruptible magma, which can contribute to the hazard assessment of large-scale pyroclastic eruptions (N11020).
- Many unexpected earthquakes with normal faulting were triggered in the southern Abukuma region by

Earthquake Engineering

the 2011 Great East Japan Earthquake (Mw9.0). We analyzed the subsurface geometry of the ruptured faults and the P-wave velocity structure around the source area by a campaign aftershock observation (Fig. 1). Their spatial relations with the geological structure, active faults, and stress field were also estimated to recognize the common properties of such triggered earthquakes (N11048).

We aim to develop strong-motion evaluation and seismic-resistant and seismic isolation design technology for the seismic assessment of electric power plants and equipment, as well as to lay a foundation for disaster risk assessment technology regarding the strategic maintenance management plans for the electricity industry.

- A fast algorithm was developed for analyzing ambient vibration records in health monitoring for large structures. Its main advantage is to stably obtain accurate results with a quarter length of data, compared with conventional algorithms. To illustrate the effectiveness of the developed scheme, we applied it to an actual-size experimental structure and validated the identified characteristic mode (N11039).
- The source rupture process of the 2011 Great East Japan Earthquake was inferred from strong-motion data by using a waveform inversion technique. The results showed the complex rupture process to interpret two distinctive strong-motion packets at a time interval of about 50 seconds observed on the acceleration records in and around Miyagi Prefecture (N11058).

Structural Engineering

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

For underground reinforced concrete structures, we developed methods that estimate the maximum deformation response of members during earthquakes by using the width of residual flexural cracks and the corrosion progress of reinforcing steel. In addition, we clarified the durability performance recovery effects by looking at epoxy resin repairs for cracked members. These results can be applied to the soundness evaluation of the underground reinforced concrete structures of thermal and nuclear power plants that experience earthquakes. (This is part of a cooperative contract study by Japanese electric power companies.) (N11005) (N11006) (N11010) (N11013) (N11045)

We have launched a field observation system on an ultra-high-voltage steel transmission tower with 142 m in height to investigate responses under natural environments, and we clarified the redundant member vibration caused by Karman vortex excitation, which develops under the limited low-wind velocity of around 4 to 5 m/s.

Achievements by Research Theme

Fluid Dynamics

We aim to evaluate the impacts of natural disasters such as strong winds, heavy snow, tsunamis, and volcanic eruptions on electric power facilities, as well as to establish mitigation measures. We also strive for flow-related technologies applicable to hydraulic, solar, and wind power generation.

- We have developed a numerical model for snow accretion on overhead transmission lines subject to wind and snow from an arbitrary direction and implemented it as a simulation code, named SNOVAL. This tool can be used to help more accurately predict galloping phenomena and heavy snow accretion, as well as to develop more appropriate countermeasures against the malfunction of transmission lines caused by these snow disasters (N11016).
- Using computational fluid dynamics technology, we have estimated the influence of building arrays on the alteration of wind profiles in urban areas. The results have quantitatively indicated the degree of wind velocity reduction and its spatial extent. This data can be used to determine a reasonable reference wind velocity in designing distribution facilities for electricity in urban areas (N11052).



Fig. 1: Geological properties in the southern Abukuma region as estimated by a campaign aftershock observation

(a) Geological map (b) P-wave velocity on the surface (c) epicenter distribution (d) depth section of the hypocenter distribution; high and low P-wave velocity anomalies correspond well with the surface distribution of metamorphic rocks and granitic rocks, respectively. Since the hypocenters are located mainly in a relatively low velocity zone, the occurrence of the triggered earthquakes may be controlled by the geological structure. The hypocenter distribution indicates that the deeper parts of the Itozawa and Yunodake faults, which were ruptured by the largest triggered earthquake (M7.0), can become convergent.

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 on biology, chemistry, and biotechnology, with an aim toward the construction and stable operation of electric power facilities, the establishment of a low-carbon society, and a reduction in the various environmental risks associated with the electric power industry.

Achievements by Research Theme

Atmospheric and Marine Environment

The target of research in this field is to develop technologies for predicting and assessing atmospheric and marine environments in order to deal with the problems of global warming and air pollution in urban areas.

The concentration of photochemical oxidants is increasing across Japan, and the causes should be clarified. We have clarified the contributions of the pollutants emitted in Japan and overseas to the atmospheric ozone, a major photochemical oxidant, by model analysis (V11053). environments and wind distribution in urban areas was developed to support the design of energyefficient cities. The applicability of the model was confirmed through a comparison between simulation results and the results of field observations in a real urban area (V11016).

would affect the cooling water intake and discharge

facilities of coastal power stations. We developed a cost-effective and nearly maintenance-free video

system that can monitor the change of coastlines and

demonstrated its applicability to the coastal areas in

front of power stations (V11040).

A computational model that can simulate thermal

River and Coastal Environment

The target of research in this field is to develop technologies for investigating, predicting, and assessing river environments associated with hydraulic power stations, as well as coastal environments near thermal and nuclear power stations, in order to solve the environmental problems related with their operation.

The factors causing the sedimentation of reservoirs with different sizes and locations were determined to support the maintenance and management of hydroelectric dams. We also developed a method of estimating the sedimentation rate of dam reservoirs using satellite data (V11039).

The erosion and sedimentation of nearshore sand

Biological Environment

In order to reduce the labor required to maintain power stations and to contribute to environmental measures, our research aims to develop methods for preventing electrical accidents caused by biofouling organisms, birds, and mammals, as well as for assessing the environmental impact of power stations on ecosystems.

- To support the stable operation of maritime power stations, we have developed techniques using genetic information and ultrasound to quantitatively detect any abundance of jellyfish or larvae of sessile organisms, such as barnacles, which can enter the channels of maritime power stations and reduce water intake (V11031) (V11012).
- To assess the coastal environment affected by sand discharge from hydroelectric dams, the effect of suspended materials on the survival of fish or the growth of seaweed was clarified (V03) (V11020).

Environmental Risk Assessment

Our aim is to develop technologies for assessing and managing environmental risks due to chemicals and electromagnetic fields as well as for measuring the quality of process effluents and utilizing wastes for recycling, in order to support environmental risk management in the electric power industry.

A selenium monitor, which can automatically measure the concentration of selenium in process effluents, was developed to manage selenium in desulfurization wastewater from coal-fired power stations. The applicability of the selenium monitor was demonstrated in actual coal-fired power stations (V11044) (Fig. 1).

Achievements by Research Theme The effect of exposure to magnetic fields was experimentally assessed using rats and animal cells including human cells. It was clarified that neither carcinogenic genotoxicity nor the developmental toxicity in the preimplantation and organogenesis stages occurred in intermediate-frequency magnetic fields generated from home appliances (V04).

Biotechnology

The target of research is to develop technologies that use micro-organisms to reduce and recycle wastes and to treat drainage water, as along with technologies that use plants to create an energy-efficient environment and that utilize renewable energy.

Cost reduction is required for the treatment of selenium-containing water discharged from coalfired power stations. Using actual drainage water, the research team demonstrated at the laboratory scale that a biological selenium treatment method developed by the laboratory, which is more costeffective than conventional methods, is useful for treating drainage water (V11059).

A practical mercury immunoassay was developed by

combining a simple pretreatment method for samples and microbiosensors to appropriately control the release of mercury (V11045).

The adjustment of the conditions of a thermal and air environment using heat pumps within agricultural factories growing plants was investigated as a means of saving energy at such facilities using heat pumps. We also proposed a technique for analyzing the air flow and temperature distribution (V11017) (V11018).



Fig. 1: Developed selenium monitor and the monitoring results of treated desulfurization wastewater at coal-fired power stations

The developed monitor (left figure) measures the concentration of selenium in process effluents using a commercially available gas sensor by reducing aqueous selenium in the sample into hydrogen selenide. Hence, the monitor enables measurement within a shorter time than that required by the official Japanese method and also enables automatic continuous measurement. The demonstration test was carried out on treated desulfurization wastewater at a coal-fired power station over three months (right figure). The fluctuations in the measured values with the monitor (\bigcirc and \triangle) between September 17 and October 21, 2011 were attributable to changes in the room temperature between day and night. After an air conditioner was installed in the measurement room, the measured values were stabilized and were in good agreement with those obtained by the official method (\bullet and \blacktriangle).

Basic Technology Subjects

Electric Power Engineering Research Laboratory

Brief Overview

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

Achievements by Research Theme

High-voltage and Insulation

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

We successfully obtained two dimensional images of rust in coated steel plates by nondestructive measurement using terahertz waves, which are electromagnetic waves in the range between visible light and microwaves. We also demonstrated that we can measure the thickness of coatings and the rust under the coatings (H11002).

Lightning and Electromagnetic Environment

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

We compiled the Application guide for transmission line surge arresters [H07] and the Guide to the Lightning Protection Design of Power Stations, Substations, and Underground Transmission Lines (Rev. 2011) [H06] through collaboration with Japanese electric power utilities. Along with the published guides for lightning protection, we established a practical lightning protection design method including related regulations for all electric equipment for power systems.

Applied High Energy Physics

We aim to develop simulation methods of pressure rising and propagation characteristics to complement the innerarcing 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 for reducing the volume of radioactive waste disposal.

- We developed a simulation method to estimate pressure rise and propagation characteristics due to short-circuit fault arcs in underground common ducts where electric cables are installed (H11034). Using both actual-size short-circuit fault testing and this simulation, we can evaluate pressure rise and propagation characteristics in a wide parameter range. This simulation can be used for improving and evaluating protection methods against disasters.
- We developed a remote measurement method using laser breakdown spectroscopy to simultaneously

obtain the concentration distributions of several elements that are indicators of degradation caused by the sea salt contamination of concrete structures (H1102) (Fig. 1).

The concentration of cobalt is important in evaluating the radioactivity level of the solidified products. We clarified the migration behavior of cobalt in plasma melting treatment of simulated waste including Ni, which will be generated during the dismantling process of nuclear power plants by simulation and experiment.





(a) Equipment setup

Fig. 1: Laser breakdown spectroscopy of the cut cross-surface of a concrete structure contaminated with salt (The detected elements are Cl, C, Ca, and Fe.)

The variation of the emission intensity of the chlorine penetrated from the saltwater-sprayed surface (depth: 0 cm) is high around the reinforcing steels, which shows that the corrosion of the reinforcing steel was induced by chlorine; the emission profile was obtained in a short time, at around 40 minutes.

⁽b) Two-dimensional distribution of the emission intensity of detected elements

Energy Engineering Research Laboratory

Brief Overview

The Energy Engineering Research Laboratory is aiming to help achieve a "smart" society that produces and consumes electric power and heat more wisely, through R&D for thermal power generation and improvement in demand-side heat utilization systems and facilities.

Achievements by Research Theme

High Efficiency Power Generation

The temperature field analysis and management technology for the hot gas path parts of gas turbines and the evaluation technology of new liquid fuels are developed to achieve further improvement in the efficiency and operability of thermal power plants.

- For developing efficient film cooling techniques for turbine blades, the effects of internal ribs on film cooling effectiveness and heat transfer coefficients were experimentally investigated, and a method for obtaining higher film cooling performance was proposed (M11002) (M11006).
- Based on the surface temperature change during laser heating treatment, a simple and non-destructive evaluation method for TBC (Thermal Barrier Coating) thermal resistance, which is necessary to estimate the surface temperature of turbine blades, was established (M11009).

Advanced Fuel Utilization

For the diversification of energy resources and the improvement of the environmental friendliness of coal-fired power plants, the expansion of fuel species and measurement methods for trace elements are under development. The catalytic decomposition of volatile organic compounds (VOCs) is also studied, aiming at the extension of applications and verification for practical use.

- For bio-oil production from microalgae using dimethyl ether (DME) as an extractant, it was found that our extraction process, which has a higher energy-saving effect than conventional processes, has a higher prospect for realized use.
- To determine gaseous boron and selenium concentrations in coal combustion gases, methods for measuring their concentrations were developed. The

JIS, and the method for selenium is adopted as a new work item of ISO.VOC decomposition technology using a ceria catalyst was applied to flue gases from printing and/or painting

method for boron is under discussion for prescription in

was applied to flue gases from printing and/or painting processes. The developed catalyst was found to have a high durability to silicone, which generally causes catalyst poisoning.

Heat Pump and Thermal Storage

We investigate and analyze the latest trends in heat exchangers, industrial heat pumps, and performance evaluation methods for various heat pumps.

The current trend regarding the industrial use of heat pumps is to develop and commercialize steam and/ or hot water production heat pumps as an alternative to steam boilers. However, as they use high GWP refrigerants, the development of heat pumps with low GWP refrigerants is needed.

Energy Conversion Engineering

Basic technologies that relate to the evaluation of thermal efficiency, fuel cells, and advanced material analysis, etc., will be developed to achieve energy savings on the demand side, as well as to improve operability and thermal efficiency on the power generation side.

To evaluate the performance of a system that converts unused energy into electric power, EnergyWin, a type of thermal efficiency analysis software, was upgraded by adding a thermo-physical properties library for low-boiling-point refrigerant (M11007).

To determine trace element compounds and to

study their behavior contained in coal and coal ash, advanced XAFS (X-ray Absorption Fine Structure) analysis using SPring-8 was developed. This analysis enables the identification of the chemical structure of trace elements at lower concentrations than ever before in only a few minutes (M11012).



- The Chemical Percolation Devolatilization (CPD) model was extended to consider tar formation, decomposition, and polymerization in primary pyrolysis and secondary
- reactions by the adhered ash particles layer on a catalyst surface in the de-NOx catalyst flow channels.



Fig. 1: Vortical structures around the film cooling hole

Vortical structures, which have strong influence on film cooling effectiveness, drastically change with the blowing ratio. It is thus important to control the unsteady vortical structures according to the blowing ratio. (Instance fields, red: crossflow, blue: film cooling flow) (time-averaged fields, arrow: velocity vectors, color: x-vorticity)

Materials Science Research Laboratory

Brief Overview

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

Achievements by Research Theme

Materials for Nuclear Energy

In order to decrease radiation exposure and secure material integrity, we develop fundamental technologies to investigate water chemistry and environmental effects on corrosion in nuclear reactors.

- We have organized an expert committee to discuss seawater effects on the corrosion of spent fuel pools at Fukushima Daiichi Nuclear Power Station and have summarized the results of the committee discussion. Mitigation methods are proposed based on the discussion and experiments.
- Zinc injection does not influence the solution of corrosion products on SG tubes under the simulated

shutdown conditions of a PWR primary system.

Measured electrochemical potential is almost independent of the Ni/NiO ratio. Then, the Ni/NiO electrode is the most appropriate candidate for a reference electrode to evaluate the electrochemical corrosion potential of reactor internals. The integrated Ni/NiO electrodes manufactured in this study exhibit almost the same theoretically expected pH value.

Materials for Thermal Power Plants

We aim to improve the efficiency of thermal power generation through the establishment of evaluation techniques for environmental resistance and structural integrity. We also contribute to improve the operating reliability of thermal power plants through the application of advanced non-destructive inspection techniques.

- Corrosion tests for boiler tube materials were performed with additive HCl on the assumption of a coal biomass co-combustion condition. The effect of HCl on corrosion behavior was experimentally examined (Q11001).
- For the unified prediction of the fracture behavior of modified 9Cr steel, a model was newly developed
- to represent the dependency of fracture energy on temperature, the deformation rate, and stress multiaxiality (Q11012).
- An ultrasonic phased-array technique was applied to the open rack vaporizers in LNG thermal power stations, and the technique could detect fatigue cracks due to thermal fluctuation (Fig. 1).

Batteries and Electrochemical Materials

Research based on materials for alternative energy and energy conservation has been conducted, focusing on the development of evaluation methods for the outdoor performance of photovoltaic (PV) systems for future mass installation and research on material for high-efficiency solid-oxide fuel cells (SOFCs).

- For the future mass installation of grid-connected PV systems, we have presented a prediction model of regional PV power generation by integrating elemental methods, such as the spatial interpolation of solar irradiance (Q11013).
- In order to make clear the SOFC performance determinative, we have evaluated the commercially available cells using an AC impedance measurement

method at open circuit voltage. The total cell resistance was found to consist of four types of resistances. Among these four, Nernst loss resistance exhibits a correlation with the changes of the gas elements and its measured values show good agreement with the calculated values, especially at a low gas flow rate (Q11010).

Advanced Functional Materials

Achievements by Research

Theme

Our mission is to explore functional electronic materials for the next generation, e.g., new superconductors and/or new organic semiconductors with extreme properties, by utilizing excellent techniques for crystal growth and by measuring basic physical properties.

- We have revealed that a fluoride substrate is far better for the epitaxial growth of Fe (Se, Te) superconductor thin films than conventional oxide substrates, and have proposed a guiding principle for selecting substrate materials.
- We have succeeded in fabricating a new type of lightemitting device made of a simple mixture of ionic liquid and light-emitting organic polymer, which can be driven by relatively low voltage and can respond very quickly.

PD (Performance Demonstration) Certification System

In order to enhance the reliability of the nondestructive evaluation for nuclear power plants, statistical analyses are made on the results of performance demonstration tests (PD tests) on the ultrasonic measurement of the depth of stress corrosion cracks in welded joints in recirculation piping systems.

Circumferential direction

Crack 1

Axial direction

An analysis of the results of all candidates passes PD tests reveals that the mean value and the standard deviation of the crack depth measurement error were 0.32 mm and 1.93 mm, respectively. However, the standard deviation of the recent three years was 1.80 mm, alluding to a technological improvement in the industry.

Through-bore

Fatigue crack

Crack



(a) Structure of an open rack vaporizer



Crack 2 Crack 3

Fig. 1: Fatigue crack in an open rack vaporizer and an example of an inspection result

An ultrasonic phased-array technique had been successfully applied to detect fatigue cracks at the bottom of the heat transfer tubes in open rack vaporizers, with high accuracy.



(b) Example of the detection of cracks in an open rack vaporizer

Fig. 2: Prototype device of the new light-emitting device made of ionic liquid and light-emitting organic polymer

By applying E=3V to the electrodes, the device turns on and the CRIEPI logo shows up. Device response speed is very fast, and a long lifetime is also expected.

Basic Technology Subjects

3. Principal New Research Facilities

Field Observation System of a Steel Transmission Tower Subjected to Wind and Seismic Actions

Background

Outline

In Japan, the aging degradation of steel transmission towers, for example, fatigue, bolt relaxation, and corrosion, are a concern because such towers are exposed to severe natural environments. We built a field observation system on a steel transmission tower in cooperation with

This system enables the ability to measure action data, such as wind speed, wind direction, temperature, humidity, atmospheric pressure, and ground acceleration, etc., along with response data such as: cable tension, axial force of a tower member, acceleration of the tower, etc., simultaneously. Measurement sensors were installed in order to evaluate response characteristics for the following three phenomena: 1) tower responses under wind and earthquake actions; 2) fatigue damage of tower members resulting from galloping;

Specifications

The following sensors and devices are included in this system;

- (1) Accelerometers: At the first, 10th, and 15th panel (two horizontal axes), the 16th panel (vertical direction), redundant members (three axes), and the ground surface (three axes)
- (2) Axial force meters: At the fourth, the seventh, and the 16th panel (four main leg members and eight bracing members), the second cross-arm (10 cross-arm members)
- (3) Three axis strain gages: At the joint plate (redundant member of the 16th panel and the second cross-arm member), a central area of a redundant member (the 16th panel)

Tokyo Electric Power Company (TEPCO) to investigate the responses and dynamic states of the tower due to external forces, including wind, earthquakes, snow and ice accretion, and others, under natural environments.

3) redundant member vibrations due to wind. We are constantly recording data at 100 Hz, and the statistics such as averages, peak values, and standard deviations of the time histories are calculated every 10 minutes from a set of observation data. Three remote industrial televisions were also installed to record cable oscillations and redundant member vibrations. In addition, a digital communications network enables the real-time check of data at our Abiko area office, in order to obtain the statistics and to control the industrial televisions.

- (4) Anemometers: At the first and the 10th panel (vane type, horizontal wind speed, and wind direction), the 16th panel (ultrasonic type, wind speeds, three axes)
- (5) Weather observation equipments: Temperature (at the sixth panel and at the ground), humidity (at the ground), rainfall amount (at the sixth panel)
- (6) Tensiometers and deflection angle meters for cables: At the second cross-arm (horizontal and vertical angles)
- (7) Movies: Responses of lower and higher cables, redundant member vibrations
- (8) Data record system and condition monitoring system

[Installed location and date]

TEPCO service area/April 2011



Target tower Photo 1: Outline of system



Recording device and display (at the observation station)



Vane-type anemometer



Fig. 1: Arrangement of sensors and devices

Carbon Dioxide Removal Atmosphere Airtight Room

Background

In the sub-surface disposal of low-level radioactive waste, a facility design that aims for the low diffusion and sorption of a radioactive nuclide is considered by its cementituous material, which is one of the engineered barriers.

The long-term evaluation of cementituous material is the one of the most important current issues. Cementituous material that shows high

Outline

Therefore, an airtight-controllable room with an atmosphere absent of carbon dioxide to the furthest degree possible for the purpose of the handling-related improvement in an examination was installed.

This room consists of low-concentration CO₂generating equipment and an airtight constant

Specifications

In the airtight constant temperature and humidity of a room with reduced carbon dioxide concentration, the diffusivity measurement examination and long-term high-temperature load test of the cementituous material can be carried out.

(1) Low-concentration CO₂-generating equipment Equipment for refining a CO₂ concentration of 10 ppm or less: CO₂ main removal equipment, compressor, air tank, activated carbon tub, CO₂ concentration sensor alkalinity easily reacts with the carbon dioxide contained in the atmosphere and deteriorates gradually inside, from the surface.

Thus, we consider it necessary to exclude the carbon dioxide, which causes the deterioration of cementituous material over a short period of time, comparatively, in the evaluation of low diffusion and sorption.

temperature and humidity room, and serves as a system for dry air, through which removal refining was carried out to 10 ppm or less in carbon dioxide with low-concentration CO₂-generating equipment after temperature and relative humidity adjustment.

(2)Equipment for an airtight constant temperature and humidity room – temperature: 20±2°C and relative humidity 60±5%: Air conditioner, temperature and relative humidity sensor

[Installed location and date]

Abiko area/May 2011



Photo 1: Appearance of an airtight constant temperature and humidity room, along with the control and monitoring apparatus



Photo 2: Appearance of low-concentration CO₂-generating equipment

Multicolor Cell-sorting and Electrical Signal Measurement System for iPS Cell Analysis

Background

The effect of electromagnetic fields on human health is an important management risk for the electric power industry and is associated with realizing a stable supply of electricity (power frequency magnetic fields) and the promotion of a safe and secure society based on the use of electricity (intermediate-frequency magnetic fields). Thus, public concern regarding this issue has been growing. To solve the above problems, the Environmental Science Research Laboratory has been addressing two important scientific themes: (1) scientific clarification of the effect of power frequency magnetic fields on childhood leukemia, by using humanized mice, in which a human complex system of blood cell differentiation is reproduced, and (2) clarification of the stimulating effect of intermediate-frequency magnetic fields on normal human cells, such as neural cells and cardiomyocytes, which derived from human induced pluripotent stem (iPS) cells. The analysis system consists of: (1) a cell-sorting system used for cell analysis and collection of target cells differentiated from human iPS cells, and (2) an electrical signal measurement system used for the real-time measurement of the activity of human neural cells and cardiomyocytes. Both systems will be indispensable for implementing the above evaluation.

Outline

The cell-sorting system mainly consists of cell sorters and can analyze up to 30,000 fluorochrome-labeled cells per second. In addition, the system can collect the live target cells from a cell population with a high degree of accuracy.

The electrical signal measurement system

can monitor the activity of neural cells and cardiomyocytes by real-time measuring of the changes in the fluorescence signals and extracellular potential. Furthermore, the stimulation of an arbitrary cell region with a specific electrical stimulus is also possible.

Specifications

- (1) Cell-sorting system (Photo 1)Main configuration
- BD FACSAria III cell sorter with six lasers that can measure up to 13 colors (fluorescent dyes) simultaneously
- (2) Electrical signal measurement system (Photo 2)
- Main configuration
- Inverted epifluorescence microscope
- Fluorescence analysis system (high-sensitivity cooled CCD camera, imaging software, etc.)
- Extracellular potential analysis system (64-ch microelectrode array [MEA], software for data analysis, etc.)
- Electrical stimulation system (isolator, micromanipulator, etc.)

[Installed location and date]

Abiko area/March 2012



Photo 1: Cell-sorting system

Photo 2: Electrical signal measurement system
High-power Testing Facilities: Impulse Current Generator

Background

At our High-power Testing Laboratory, to evaluate the safety and performance of electric power equipment and apparatus, we employ short-circuit tests and short- time withstand current tests of circuit breakers, etc., along with AC and DC arc resistance tests of insulator sets, cables, and transformers. An impulse current generator is an important piece of equipment at our High-power Testing Laboratory. A lightning voltage or current impulse generated by an impulse generator can be super-imposed on an AC wave for the short-circuit test for the performance evaluation of arresters or apparatus for the lightning protection of distribution lines. We also upgraded the current impulse generator to increase the available current for tests simulating lightning strikes with high energy.

Especially, it can generate high-peak current

impulse, which is necessary for the tests of new

Outline

Specifications

Rated voltage: 800 kV; maximum charging energy: 240 kJ

This renewed impulse current generator will be

used for the AC/impulse tests and high-current

impulse resistance tests of single arresters.

Impulse current waveform: (front time/time to half value [μs]) 8 (±10%)/20 (±10%) Maximum impulse current: ±25 kA (in case of an arrester: rated voltage 98 kV), ±50 kA (in case of an arrester: rated voltage 8.4 kV) Impulse voltage waveform: (front time/time to half value [μs]) 1.2 (±30%)/50 (±20%) Maximum impulse voltage: ±800 kV Structure: All-weather type (outside installation), main capacitors separated with gaps Measurement equipment: Resistor voltage divider for lightning impulse: 1,000 kV; coaxial shunt: 200 kA

arresters.

[Installed location and date]

Yokosuka area/July 2011



Small Zeolite Column Test Equipment

Background

During the first phase of the Fukushima Daiichi Nuclear Power Station accident, it was a highpriority issue to establish a cooling water recycling system, through which contaminated water of about 0.2 million cubic meters, accumulated in the reactor or turbine buildings, can be decontaminated and desalted, and then with the resulting pure water used for reactor cooling once again.

It was thus necessary to understand the effect of the sea salt and oil content in the contaminated water on the Cs adsorption properties of zeolite. Further, this system had to have a high throughput capacity of around 1,200 m^3 /d. It was our urgent task to stably operate the Cs adsorption apparatus (KURION system).

Hence, in order to support the design and operation of the decontamination system, functional small-scale zeolite column testing equipment in which the several kinds of zeolites can be tested was installed in CRIEPI.

The dynamic characteristic of the system such as the breakthrough curve^{*} is estimated using this equipment. Using these results, a simulation code is developed that can predict the Cs removal performance of the actual system.

Outline

OSingle-column/series-columns test: Both the single-column test for the verification of the developed calculation code and the series test consisting of four columns modeled after the actual system can be conducted.

OMerry-go-round system: The column-changing system applied to the actual system can be simulated by changing valve operation. (After the top column adsorbs an adequate amount of Cs, the top column is dismantled from the system and the second column is moved to the top position, and the new column is installed at the third position.)

OLong-term operation: As breakthrough is attained after more 24 hours in some cases of Cs concentration in the contaminated solution, an auto feeder and sampling system are introduced for the long-term operation.

Specifications

(1) Column

- Transparent column made of acrylic resin (two kinds of diameters: 3 cm and 5 cm), with easy de-installation functionality (2) Measuring system
 - At the feed inlet, a flow meter (Aichi Tokei Denki Co., OF05ZZWIN) and a pressure gauge (Yokokawa Electric Co., FP201) are equipped.

(3) Sampling system

At the outlet of the column, the sample solution is collected at certain intervals through the open and close of the solenoid valve, and the collected solution is transported to the auto sampler (EYELA DC-1500) by tube pump (EYELA SMP-23) and finally collected in the 15 cm^3 sample tube.

These systems are equipped at each of the three lines, and four series-column tests can be conducted.

[Installed location and date]

Komae area/May 2011



Photo: Small zeolite column test equipment

"Breakthrough" refers to the fact that the outlet concentration of Cs was the same as the inlet concentration of Cs through the saturation adsorption capacity of the column. A breakthrough curve can show the relationship between the time and the ratio of outlet concentration to inlet concentration.

Small Glass Melter Test Facility

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Outline

This facility was installed to conduct fundamental tests concerning the vitrification process of a reprocessing plant, where liquid waste containing high-level radioactive material (high-level liquid waste) is consolidated into the chemically stable glass matrix.

In particular, the observation of the behavior of the cold cup on the glass melting pool is the primary objective of this equipment, where dried waste is

Using this facility, several types of basic data will be obtained concerning the chemical reaction generated in the cold cup in the glass melter in which the high-level liquid waste is consolidated into the glass matrix, and the main component is the lab-scale small glass melter into which the simulated waste solution and glass material can be continuously fed. slowly mixed with the molten glass. As the condition of the cold cup could affect the glass production rate and the properties of the produced glass, the effect of the glass melting speed or the control of temperature on the cold cup condition is closely studied.

The stabilization of the cold cup condition is considered to be most important factor in the glass melter's operation, and the results obtained at this facility will be useful for the reprocessing plant.

the same brick as that of the actual melter, and glass is heated using Joule heating (electric current is passed directly into the molten glass). The simulated liquid waste and glass material can be fed together, and the cold cup can be generated on the molten glass pool. A sample of the cold cup can be obtained without stopping the melting operation.

The material of the glass melter is made from

Specifications

Type of glass melter: Liquid-feed Joule heating ceramics melter (LFCM) Brick materials that contacts molten glass: Monofrax K-3 Electrode material: NCF690 (Inconel alloy) Casing: sus304 Surface area of molten glass: 0.0225 m² (150 mm × 150 mm) Depth of molten glass: Low level 132 mm, high level 150 mm Operating temperature: 1,150°C (max: 1,200°C) Feed: Continuous type Glass drain: Batch type

[Installed location and date]

Komae area/February 2012



Photo: Small glass melter test facility



4. Activities The activities of the CRIEPI in FY 2011 are outlined below.

Human Resources

1

The CRIEPI employs 835 people as of 31st March, 2012. 736 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. 366 people working at the CRIEPI have a Ph.D. Of these, 77% and 10% have an engineering and science background respectively.

2 Research Reports

A total of 595 CRIEPI research reports were produced in FY 2011. Of these, 464 were research reports and 131 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* can be downloaded from the CRIEPI's website.

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

3 Presentation of Research Papers

A total of 1,407 research papers were presented in bulletins of academic societies and academic journals and at academic conferences. Of these, 383 papers were peer reviewed. Fig. 3 shows the breakdown of research papers by subject field. The titles of these papers are contained in the research paper database under "Research Results/Reports, etc." on the CRIEPI's website.





Fig. 2: Breakdown of reports by subject field



Fig. 3: Breakdown of research papers by subject field



Fig. 4: Classification of research partners

Joint Research

projects were conducted in FY 2011. As shown in Fig. 4, universities and central governmental research institutes, etc. accounted for 35% and 19% of the research partners



Fig. 5: Main partners in research cooperation agreements The European Atomic Energy Community (EURATOM) is based in Europe.

Main International Cooperation/ 4-2 Interchange Schemes

The CRIEPI has been moving ahead with joint research, information exchange and human interaction with a number of research institutes overseas. Fig. 5 shows the main overseas institutes with which the CRIEPI has concluded an international agreement for cooperation. Table 1 (p.110) lists the main partners of the CRIEPI for international cooperation / interchange.

4. Record of Activities The following is the summary

Table 1 Main international cooperation/interchange partners

Main Partners for Research Cooperation Agreement

Asia				
Korea Electric Power Research Institute (KEPRI)	Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand			
Korea Electrotechnology Research Institute (KERI)	China Electric Power Research Institute (CEPRI)			
Korea Power Exchange (KPX)	Sate Grid Electric Power Research Institute (SGEPRI), China			
Korea Smart Grid Institute (KSGI)	Shanghai Jiao Tong University (SJTU), China			
Taiwan Power Company (TPC)	Indonesia State Electricity Corporation (PT PLN), Persero			
Nuclear Science and Technology Association of Taiwan (NuSTA)				
USA				
Electric Power Research Institute (EPRI)	Southwest Research Institute (SwRI)			
Europe				
European Atomic Energy Community (EURATOM), EU	Federal Institute for Materials Research and Testing (BAM), Germany			
National Cooperative for the Disposal of Radioactive Waste (NAGRA), Switzerland	International Atomic Energy Agency (IAEA)			
French Atomic Energy Commission (CEA)				
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)	Surfactant and Bioenergy Research Center (SBRC), Bogor Agricultural University (IPB), Indonesia
APEC Climate Center (APCC), Korea	
North America	
Regional Economics Applications Laboratory (REAL), University of Illinois	New Mexico Institute of Mining and Technology
Electric Power Research Institute (EPRI)	United States Nuclear Regulatory Commission (USNRC)
Idaho National Laboratory (INL)	Lawrence Berkeley National Laboratory (LBNL)
National Center for Atmospheric Research (NCAR)	Nuclear Waste Management Organization (NWMO), Canada
University Corporation for Atmospheric Research (UCAR)	
Europe	
French Atomic Energy Commission (CEA)	RWTH Aachen University, Germany
Électricité de France (EDF)	Institute for Transuranium Elements (ITU), Germany
National Agency for Radioactive Waste Management (ANDRA), France	Forschungszentrum Karlsruhe GmbH (FZK), Germany
Swedish Nuclear Fuel and Waste Management Company (SKB)	Gesellschaft für Nuklear-Service mbH (GNS), Germany
Studsvik Nuclear, Sweden	Federal Institute for Materials Research and Testing (BAM), Germany
The Von Karman Institute for Fluid Dynamics, Belgium	Forschungszentrum Dresden - Rossendorf (FZD), Germany
National Cooperative for the Disposal of Radioactive Waste (NAGRA), Switzerland	Federal Ministry of Economics and Technology (BMWi), Germany
VaasaETT Global Energy Think Tank, Finland	Leibniz Institute for Solid state and Materials Research (IFW), Dresden
POSIVA, Finland	Friedrich Schiller University Jena, Germany
Radioactive Waste Repository Authority (RAWRA), the Czech Republic	Polytechnic University of Turin, Italy
Comenius University, Bratislava	National Research Council, Italy
International Atomic Energy Agency (IAEA), Austria	University of Twente, Netherlands
Oceania	
Geodynamics Ltd.,Australia	ZeroGen Pty Ltd.,Australia
Curtin University, Australia	
Other (involvement of institutes from multiple countries)	
Mont Terri Consortium	Halden Reactor Project

Participation in International Organizations

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

International Electric Research Exchange (IERE)

of the activities that the CRIEPI was engaged in FY 2011.

5 Forums, Seminars and Other Events

The following forums, seminar and open laboratory were organized in FY2011.

CRIEPI Forum 2011 (special version-<part I>) Special forum on the restoration and recovery efforts following Fukushima Daiichi Nuclear Disaster. November 10th, 2011, IINO Hall, Tokyo

Energy and Environmental Forums November 26th, 2011, Osaka Municipal Lifelong Learning Center, Osaka January 21st, 2012, Kanagawa Plaza for Global Citizenship ("Earth Plaza"), Yokohama

6 Industrial Property Rights

170 patents were registered and 97 patent applications were made in FY 2011. 11 patents or know-how* were newly licensed in FY 2011.

7 Software

The CRIEPI has its own software registration system for the management of copyright. A registered software may be licensed to electric companies, other profit-making enterprises and universities in response to their request. The number of new software registrations and the number of new licenses awarded were 92 and 299 (716 copies) respectively.

8 Other

The CRIEPI or its executives and regular employees wrote or edited five major books in FY 2011 while executives and regular employees received external awards on 49 occasions (total of 67 persons). The "CRIEPI's World Wide Information Service" (http://criepi.denken.or.jp/) is a free and publicly accessible service that has been running since FY 1995. Although the above sites are offered in Japanese, the CRIEPI also offers an English language site with wealth of information. (http://criepi.denken.or.jp/en/index.html) They provide access to the summaries of a number of non-confidential research documents and annual research reports, as well as publications such as the "CRIEPI News" (http://criepi.denken.or.jp/research/news) which is a series of leaflets that uses plain language, photographs, and illustrations to introduce the research findings of the CRIEPI in a way that is easy for the general public to understand.

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

Locations



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