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FEATURE

Assessment Technologies for the Safe and Sustainable Society

Research Hotline

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In Brief

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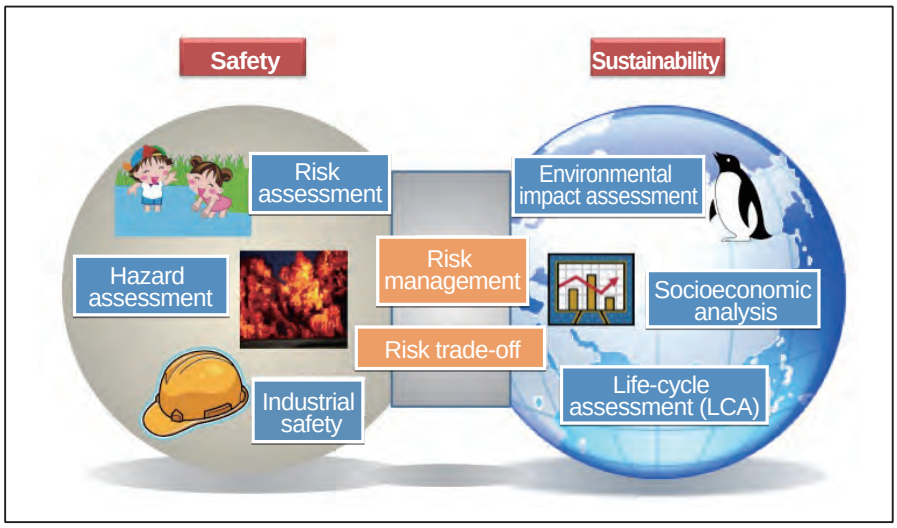
Below: A model (1/6 scale) of the underground explosives storage facility being buried underground (p. 10)

Assessment Technologies for the Safe and Sustainable Society

The Research Endeavors of the Research Institute of Science for Safety and Sustainability

Introduction

The Research Institute of Science for Safety and Sustainability (RISS) was established on April 1, 2008, with the research goals of developing methods for the scientific assessment of safety and sustainability and contributing to innovation.



The research endeavors of the Research Institute of Science for Safety and Sustainability: Assessments of safety and sustainability

Risks and risk trade-offs

New technologies and systems are, on the one hand, looked upon with great expectations for innovation, but on the other hand, negative effects of their introduction are also a matter of concern. In addition, there is also the problem that because of their novelty, insufficient data are available to adequately assess their risks. To deal with these problems, we are promoting research on risk assessment and risk management methods taking the case of industrial nanomaterials as an example. We have also begun research on the risk management of radioactive substances and decontamination in Fukushima Prefecture, making best use of the expertise that we have acquired through risk assessments of chemical substances.

The risk of a chemical substance is defined by the hazardousness of the chemical substance itself, and by the possibility of coming into contact with that particular chemical substance (referred to as exposure). Up to now, we have primarily been analyzing the exposure situations of groups (humans and organisms) to chemical substances from industrial sources on the scale of a region or a city, but we are currently developing techniques to analyze the exposure of individuals to chemical substances released by consumer products in everyday living spaces.

When the risk of a chemical substance is found to be high, either its use is stopped or the substance is replaced with another substance. Sometimes, however, the result is the appearance of a different risk. This is called a risk trade-off relationship. It is highly important that this risk trade-off is understood when making any decision regarding the use of a chemical substance, and we are therefore conducting the necessary research for this purpose.

Some chemical substances hold the possibility of causing a fire or explosion if they are misused. We are thus developing methods to accurately assess the risk of a fire or explosion of these chemical substances so they can be used safely. We are also pursuing research aimed at mitigating the impact and lessening the damage in the event that such an accident occurs by chance while explosives and flammable gases are being used.

When introducing a new technology or system, an assessment should be made to clarify whether or not it is environmentally, economically, and socially sustainable. In this respect, we are taking biomass as an example and are aiming to determine the appropriate form and scale of a system that uses biomass for energy or as an industrial material in order for it to be sustainable. Moreover, in developing techniques to

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quantify environmental impacts, which are needed in the process of this research, we are, for example, incorporating the newly highlighted environmental impact assessments for water consumption and land use in addition to those for global warming and resource consumption so as to develop a highly sophisticated assessment method.

Conclusion

As described above, assessments of safety and sustainability are required in many situations. We are actively working to discover a universal methodology through individual case studies and are committed to the ongoing establishment of safety science.

Deputy Director-General of
Environment and Energy
Hiroki YOTSUMOTO

Supporting the Safety Management of Carbon Nanotubes (CNTs)

The necessity of safety management of CNTs

A CNT is a very thin tube-shaped carbon material with a thickness between 1/1,000 and 1/100,000 that of a human hair. Its practical application as an innovative material with high mechanical strength and electrical and thermal conductivity is awaited in a wide range of fields. On the other hand, because it is a novel material, demand has arisen for assessments of its safety and its proper safety management. We are responding to this situation by promoting the development of methods to assess the hazardousness and understand the exposure situation of CNTs, focusing on the effects of CNT inhalation in workers handling CNTs.

Methods to assess the hazardousness of CNTs

While the most reliable test to assess the effects of inhalation of CNTs is the inhalation exposure test, in which

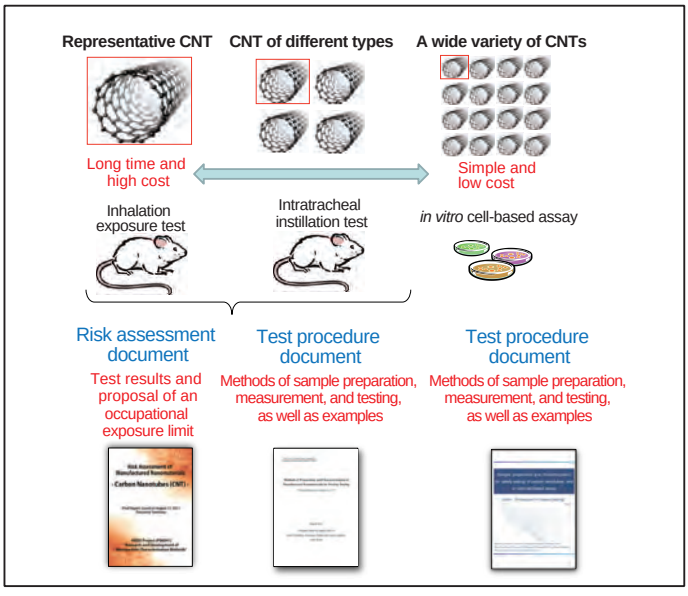

Fig.1 Framework of hazard test

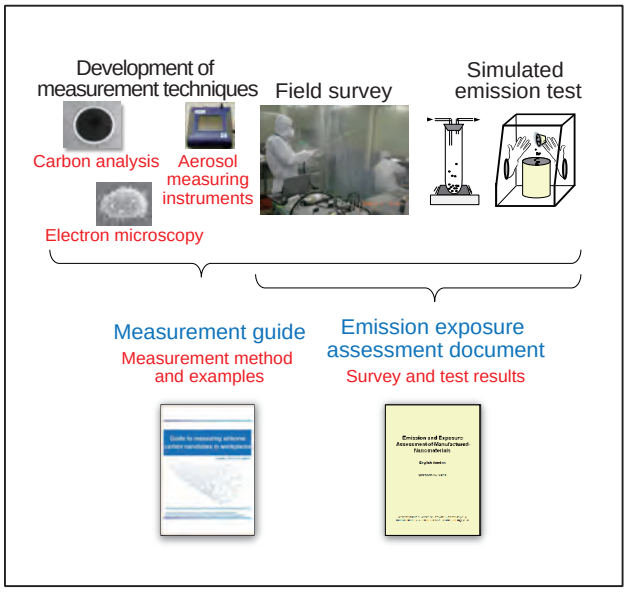

Fig.2 Framework of exposure assessment

experimental animals are exposed to CNTs through inhalation, this test requires special facilities, a high cost, and a long time period. For this reason, as a much simpler test we developed a framework that effectively utilizes the intratracheal instillation test, which directly administers CNTs dispersed in a liquid into the experimental animal's trachea using a syringe and others, and the *in vitro* cell-based assay, which is simple, fast, and does not use any animal (Fig. 1). The results obtained from animal tests were used to propose an occupational exposure limit for businesses that handle CNTs to promote safety management, and to publish a risk assessment document. Additionally, the test procedure documents of the sample preparation method and characterization of CNTs were published in order to support appropriate CNT hazard assessments.

Method for understanding CNT exposure situations

To make it possible to understand a CNT exposure situation, we have developed measurement techniques to measure released CNTs and are conducting surveys of fields in which CNTs are handled as well as simulated emission tests (Fig. 2). So far we have published a measurement guide and an emission and exposure assessment document to support safety management by businesses.

This research is the fruit of a project commissioned by the New Energy and Industrial Technology Development Organization, and part of the research was also performed through our participation in the Technology Research Association for Single Wall Carbon Nanotubes (TASC). The documents introduced above are available on the RISS website via the following link:

https://www.aist-riss.jp/main/modules/product/category0001.html?ml_lang=en (English page).

Substance Flow and Emission Analysis Group, RISS
Isamu OGURA

Risk Assessment Strategy Group, RISS
Katsuhide FUJITA

Research on the Risk Management of Radioactive Substances in Fukushima — From evaluation of the effectiveness and cost of decontamination to assessment of external doses —

Confronting an actual risk management problem

How should we decontaminate the vast area contaminated by the radioactive substances released from the Fukushima Daiichi Nuclear Power Plant disaster? Substantial costs and labor are required for Fukushima decontamination. The method and efficiency of decontamination vary according to the environment and even when it has been completed, the radiation dose will not immediately return to the level before the accident in all places. In the face of these decontamination problems, we created a research group in April 2012 to tackle the ways in which decontamination should be carried out with the help of in-house and outside researchers. Since then, we have been conducting problem-solving-oriented research with the aim of providing information that can serve as a basis for policy discussions leading to the proper risk management of and measures against radioactive substances.

How much will decontamination cost? And how effective will it be?

Our first task was to calculate the effectiveness and the cost of decontamination in Fukushima Prefecture. We systematically compiled and combined a wide range of knowledge and expertise on, for example, air dose rates, land use, decontamination efficiency, and the unit costs of decontamination options and utilized a geographic information system (GIS) to analyze the effectiveness and cost of decontamination. The results showed that the cost of decontamination, including the cost for temporary storage and interim storage facilities, would be roughly 1.8 trillion yen for the "special decontamination areas" alone and if the cost for the "intensive contamination

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survey areas" was also added, the estimated total cost would reach a maximum of about 5 trillion yen for the entire Fukushima Prefecture. At the same time, the results also indicated that even after decontamination, the air dose rate in some areas would not be sufficiently lowered in the short term to meet the government's target value (Fig. 1). [1] [2]

Understanding and estimating realistic external doses

To formulate effective external dose mitigation measures and eliminate anxiety about radiation, we need to gain knowledge on realistic external doses and establish a method for their estimation. By using a portable personal dosimeter system called the D-shuttle, which was developed by AIST [3] and is manufactured by Chiyoda Technol Corporation, anyone can find out where, when, and how much radiation they have been exposed to. We are presently combining data from the D-shuttle, the global positioning system (GPS), and behavior records to quantitatively understand the relationships between air dose rates, personal doses, and individual behavior so as to develop a practical method for estimating external doses considering behavior patterns of individuals (Fig. 2).

Risk Assessment Strategy Group, RISS
Wataru NAITO

Geo-Environmental Risk Research Group,
Institute for Geo-Resources and Environment
Tetsuo YASUTAKA

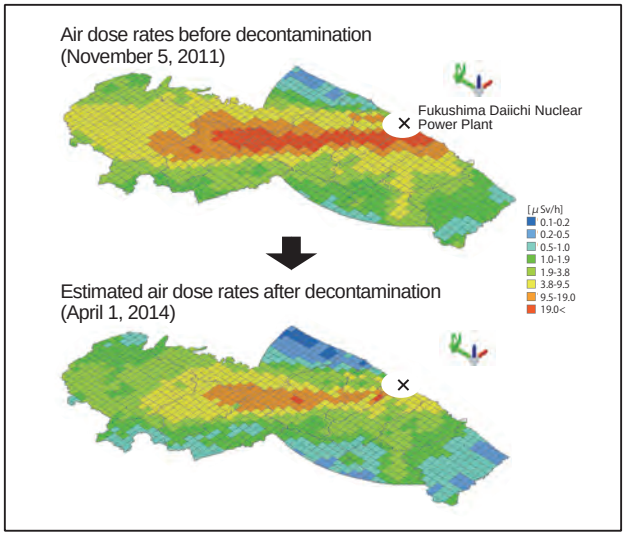


Fig. 1 Use of the GIS to integrate and analyze data on air dose rates, land use, and decontamination efficiency for each type of land use to estimate the geographic distribution of the effectiveness and costs of decontamination[1][2]

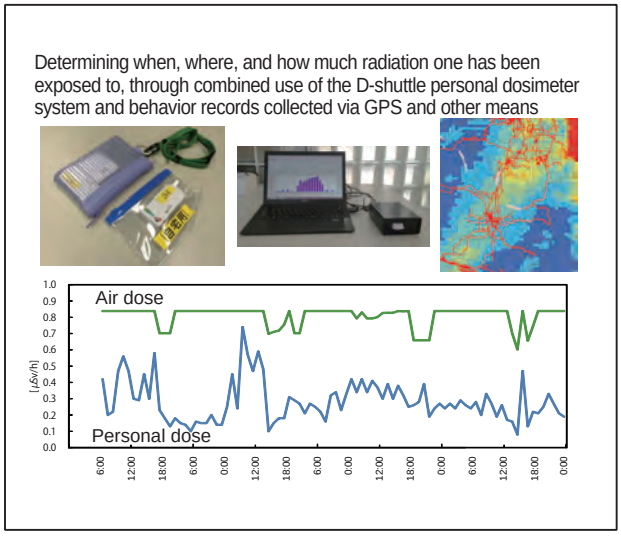


Fig. 2 Understanding the relationship between personal dose and air dose by making use of the D-shuttle and GPS/GIS

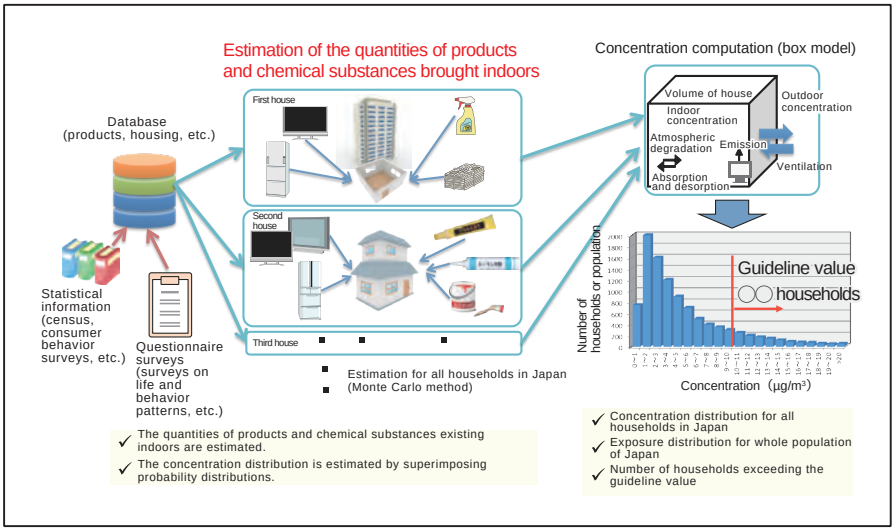
References

[1] RISS website: "Analysis of Decontamination Effects and Their Cost"
http://www.aist-riss.jp/main/modules/research/content100.html?ml_lang=en
[2] T. Yasutaka *et al.*: *PLoS ONE*, 8(9), e75308 (2013).
[3] R. Suzuki: "Development of small radiation dosimeter: Long battery life of more than 1 year on a button cell battery," *AIST TODAY* 2012-4 No. 46, p. 23 (2012).

Development of a Tool to Assess Exposure to Chemical Substances Released by Consumer Products

From environmental exposure to consumer product exposure

Human exposure to chemical substances can not only take the form of environmental exposure via air, water, etc. and occupational exposure at factories and other places that handle chemical substances, but also through products that people use in their daily lives (consumer products). Exposure via the environment, such as air pollution from factory stacks, has traditionally been the main problem, but the health impacts of exposure to chemical substances released by consumer products in the everyday environment, as represented by the so-called sick building syndrome, have recently become a focus of concern. Our research has concentrated up to now on the development of models and tools related to environmental exposure occurring via the air, water, and so on, but we are now placing a strong emphasis on the development of methods and tools applicable to exposure from consumer products.



Computation method of the indoor exposure assessment tool (iAIR)

Characteristics of a tool currently under development

We are currently developing a tool that estimates human exposure to chemical substances contained in consumer products existing in Japanese homes. This tool can handle exposure to compounds (detergents, pesticides, etc.) and finished products (television sets, furniture, etc.), and takes into consideration inhalation exposure via indoor air, dermal exposure via direct contact with these products, and oral exposure via direct contact and house dust. One superior characteristic of our tool is that this software comes with an internal database. It has a built-in data set that mirrors the present conditions in Japan with basic information on housing, such as the types of homes and floor areas, as well as basic information on people, such as body weight and respiratory volume. With regard to information on chemical substances and products, we are planning to not only prepare a default data set for a number of representative substances, products, and usages, but also to develop a system with excellent maintainability so that users will be able to easily add new data.

Present outcomes and future plans

Concerning exposure from consumer products, we have been giving priority to indoor inhalation exposure in our research up to the present time. We have now developed an indoor exposure assessment tool (iAIR) as software that can be operated on a personal computer. It is publicly available on the RISS website and can be downloaded free of charge. Presently, along with the further refinement of our indoor exposure assessment method, we are also promoting the development of assessment methods for dermal and oral exposure. If

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everything proceeds as planned, we are expecting to complete the development of a tool that can comprehensively estimate exposure from the three paths–inhalation, dermal, and oral–by around 2016. Exposure from consumer products is currently overestimated using extreme values to be on the safe side, because there are no tools nor relevant data that can be used to assess exposure from consumer products. When our tool is completed, it is expected that administrative bodies, businesses, and other related parties will be able to make satisfactory assessments based on practical scenarios.

This research is a commissioned project of the Ministry of Economy, Trade and Industry.

Environmental Exposure Modeling Group, RISS
Haruyuki HIGASHINO

Risk Trade-off Assessment of Flame Retardants and Metals

The problem of risk trade-offs among chemical substances

AIST developed risk assessment methods applicable to chemical substances between 2001 and 2006 and drew up detailed risk assessment documents for 27 substances. While this led to efforts by businesses in Japan to mitigate the risks associated with these chemical substances, such substances were increasingly replaced with other substances and concerns began to arise that these substitute substances might present higher risks than the original substances. This type of relationship is called a risk trade-off. Given this situation, AIST worked on the development of a risk trade-off analysis method from 2007 to 2011 to ensure the optimal management of chemical substances.

Focusing on the substitution of substances targeted by the European Directive

In Europe, EU Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) took effect in 2006. The Directive restricts the use of six substances: lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls (PBBs), and polybrominated diphenyl ethers (PBDEs). Businesses in Japan that exported their products to Europe have also found it necessary to seek substance substitution and as a result, the replacement of lead solders with lead-free solders and bromine-based flame retardants with phosphorus-based flame retardants and other flame retardants has been promoted. We performed risk trade-off assessments of these substance substitution cases.

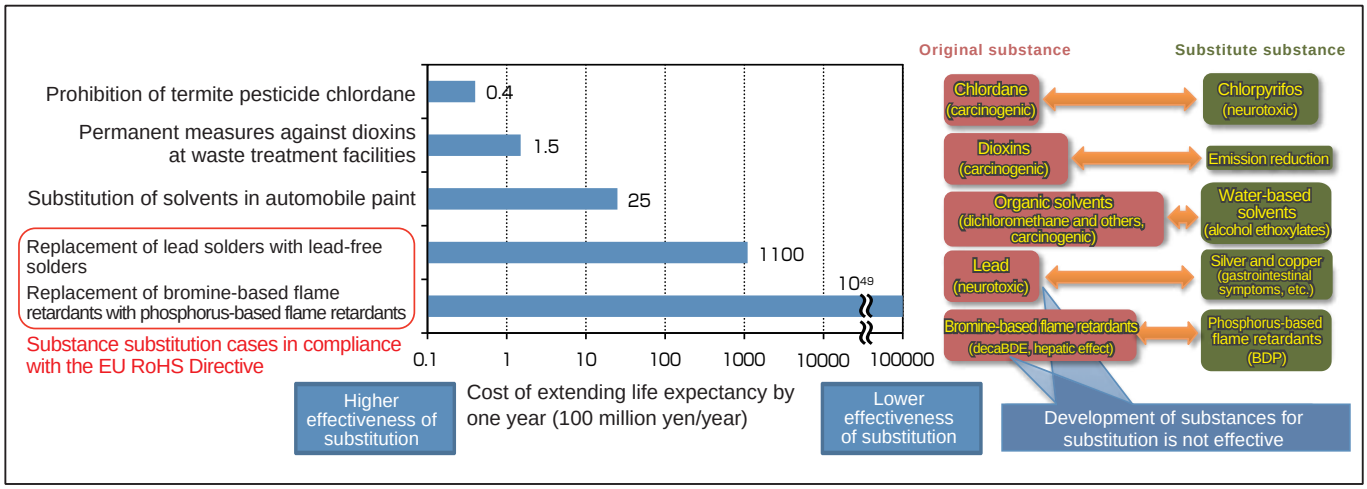
Execution of risk trade-off assessments

The availability of information on the hazard of and exposure to substitute substances was comparatively lower than that for the original substances. For this reason, there were problems such as a lack of information on the emission amounts of substitute substances and their behavior in the environment, and the substitute substances could not be compared with the original substances because the hazard of the substitute substances was unknown. In response to this situation, we created emission scenarios that take the physical properties and the conditions of the manufacturing procedures into consideration and performed exposure analyses. We also created tools that can estimate hazard even when data are lacking, as in the case of the substitute substances, and formulated a method that makes it possible to scientifically and quantitatively compare an original substance and substitute substance on the same index. Moreover, we performed a socioeconomic analysis and calculated the cost of extending human life expectancy by one year, then compared this with a sample of past measures (see the figure). As a result, we found that although substance substitution could mitigate the risk somewhat, for the country as a whole there were concerns that the loss cost might be extremely large. We are

supporting the efforts of businesses in substance substitution through the creation and publication of risk trade-off assessment documents, assessment guidelines, and a wide range of tools and models.

This research is a commissioned project of the Ministry of Economy, Trade and Industry.

Substance Flow and
Emission Analysis Group, RISS
Kiyotaka TSUNEMI



Results of socioeconomic analysis based on risk trade-off assessments

Thermal Analysis of Explosive Silver Compounds

Assessment of explosive substances

The explosibility of a chemical substance is closely connected to the energy of its exothermic decomposition reaction. For this reason, taking measurements of the exothermic decomposition energy and the exothermic onset temperature using thermal analysis equipment are the most important means of assessing the risk of explosion. The most popular method of analysis for this purpose is differential scanning calorimetry (DSC). In this method, a sample of about 1 mg is sealed in a pressure-resistant metal sample container, the temperature is increased at a certain heating rate (for example, 5 °C/min), and the temperature of the exothermic decomposition is measured.

According to the dangerous goods classification tests defined by the United Nations, in the case of an organic compound, if the result of the DSC test indicates that the value of the exothermic decomposition energy is less than 800 Jg^{-1}, there will be no need to conduct a large-scale explosion risk assessment test. The DSC test is also used in Japan to classify the dangerous goods in Category V, self-reactive substances, under the Fire Service Act. Moreover, many chemical companies are using the DSC test to make explosion risk assessments.

The DSC test is widely conducted, as described above, but the assessment of inorganic compounds is difficult and requires technical knowledge. An example assessment of explosive silver compounds is introduced below.

Explosive silver compounds

Recently, we have been receiving an increasing number of inquiries and research requests related to explosive silver salts. This is probably because of the

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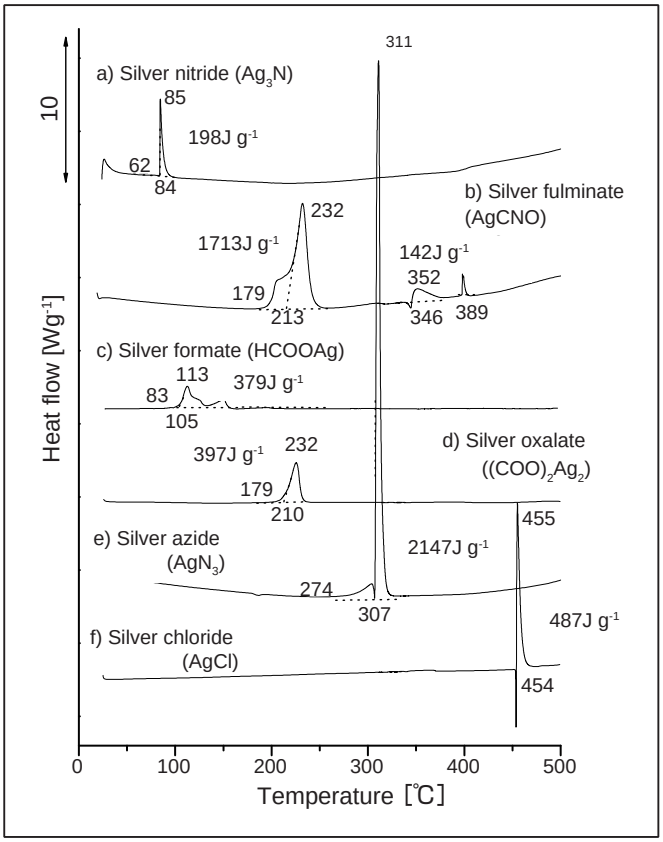
increased interest in silver nanoparticles. Silver has a bactericidal effect and also shows promise as a printing material. The idea of using a silver compound with an anion that can be gasified to create silver nanoparticles would seem to be reasonable. However, caution is needed since such silver compounds have explosibility.

The figure shows the results of DSC tests performed on explosive silver compounds. The vertical axis represents the heat flow and the horizontal axis the temperature. In these assessments, increased risk is indicated by a lower exothermic onset temperature and also by a larger exothermic decomposition energy (equivalent to the area of exothermic peak in a DSC profile). In addition, a sharp rise in a DSC profile indicates the occurrence of extremely rapid decomposition.



DSC profiles of explosive silver compounds

Silver nitride and silver azide showed very distinctive results. As can be seen in the figure, these two substances decomposed very rapidly. Silver nitride is accidentally created when a silver compound is dissolved in aqueous ammonia and is an extremely dangerous substance that will explode at the slightest stimulation. However, its exothermic decomposition energy is not large. On the contrary, silver azide not only had a large exothermic decomposition energy but also extremely rapid decomposition. Nevertheless, its exothermic onset temperature was high, thus giving it stability, and if treated with caution it can be handled on the scale of grams. Silver fulminate is also a well-known explosive substance. In contrast, although the explosibility of silver formate and silver oxalate are not so well known, they are substances that need to be handled with caution, according to the DSC profiles. What about silver chloride? The intense heat at around 450 ℃ is actually the heat from the reaction occurring between the stainless steel of the sample container and the chlorine content of the melting silver chloride and is not heat from the decomposition of the silver chloride itself, revealing that it does not have explosibility.

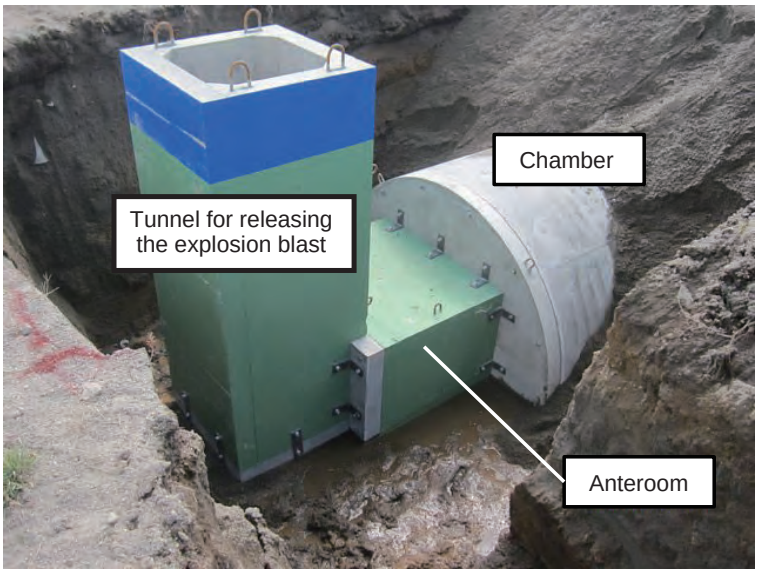
Our next plan is to systematize a method that can also appropriately evaluate the explosibility of inorganic compounds.

Energetic Materials Group, RISS
Takehiro MATSUNAGA

Research on an Explosion Blast Reduction Technology — Enhancing the safety of explosives storage facilities —

Securing public safety

The word *explosion* is familiar to everyone. Among many explosive substances, those with industrial applications such as gunpowder and trinitrotoluene (TNT) are referred to as explosives. If a disaster caused by explosives occurs, damage may be inflicted not only on those responsible for the explosion but also on the general public as well. For this reason, explosives are restricted in Japan under the Explosives Control Act to ensure public safety. The Explosives Control Act prescribes the distance (safety distance) between an explosives storage facility and buildings that need to be protected (protected properties) in relation to the quantity of stored explosives and the type of protected properties. If building lots are expanded and residences are built closer to an explosives storage facility, however, there may be cases in which the required safety distance cannot be secured. In these circumstances, if it can be judged to be scientifically reasonable and sufficiently safe, the problem may be resolved by revising (shortening) the safety distance between the explosives storage facility and protected properties. Given this situation, we are actively promoting the research and development of an explosion blast reduction technology that can ensure public safety even in cases where the safety distance has been shortened.



A model (1/6 scale) of the underground explosives storage facility being buried underground

Reduction of an explosion blast

Here we would like to introduce a study that was carried out on an underground explosives storage facility. This facility was designed in such a way that a room for storing explosives (chamber) and a room connected to the chamber (anteroom) were built underground and a pathway for an explosion blast (a tunnel to release the energy of an explosion blast) was constructed from the anteroom to the surface of the ground. In the case of an aboveground explosives storage facility, if an explosion should occur its energy will be released in horizontal directions, which is why a sufficient safety distance to protected properties is prescribed. On the contrary, in the case of the underground explosives storage facility described above, because it is surrounded by the ground, the energy of an explosion will pass through the anteroom and the tunnel and be released into the air. The horizontal expansion of the explosion energy will therefore be limited and the explosion blast will be attenuated. Thus, by constructing an explosives storage facility underground, it may be possible to reduce the explosion blast and shorten the safety distance.

Present outcomes and future plans

To confirm the explosion blast reduction effect and the possibility of shortening the safety distance of the underground

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explosives storage facility, we conducted demonstration experiments (see figure) using a maximum of 78 kg of explosives (performed as a commissioned project of the Ministry of Economy, Trade and Industry) between FY2007 and FY2010. As a result, we determined that the safety distance for an underground explosives storage facility can be shortened to about 60 % of that for an aboveground facility. Based on this outcome, in FY2012, the Explosives Control Act was partially amended (Ordinance of the Ministry of Economy, Trade and Industry No. 39 of 2012) and an article related to underground explosives storage facilities was added to the ordinance for enforcement; namely, Article 25-2 of the Ordinance for Enforcement of the Explosives Control Act (Position, structure, and equipment for a Grade 1 underground explosives storage facility).

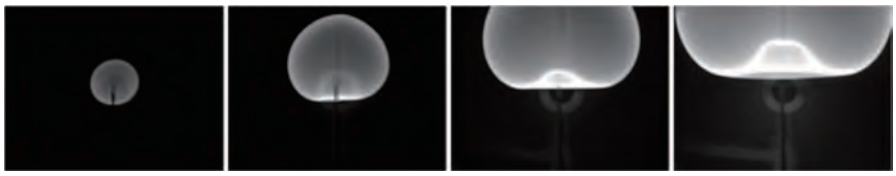
The explosion blast reduction technology introduced here is only one of many possible technologies. We are committed to our ongoing research activities with the aim of ensuring public safety and plan to continue to reflect the results of this research in the revision of laws and regulations.

Explosion and Shock Waves Group, RISS
Tomoharu MATSUMURA

Fire and Explosion Risk Assessment of Various Gases and Research on Their Safe Use

For the safe use of various gases

The demand for fire and explosion risk assessments and technologies for the safe use of various gases is increasing due to a number of reasons, including the need to prevent accidents involving high-pressure gases that have recently been on the rise, and to establish standards for the effective use of next-generation refrigerants that take global warming and ozone layer depletion into consideration as well as standards for the realization of a hydrogen society. By making best use of the experience gained through leakage and diffusion behavior research conducted using the only large flammable-gas wind tunnel in Japan and through large-scale fire and explosion tests conducted in the field, we are engaged in research commissioned by the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO) on the safe use of various gases.



A scene of difluoromethane (R32) burning (equivalent ratio 1.2; from left to right: 100, 200, 300, and 400 ms after ignition) [1]
The flame that normally spreads out into a sphere rises during combustion due to the slow burning rate.

For research on high-pressure gases, we collected basic data needed for numerical computation with the objective of developing an impact assessment tool that can be used at the time of a fire or an explosion accident caused by flammable gas at a chemical plant or other facility. The basic data were collected by observing how hydrogen or propane gas fires accelerate over time and by observing the impacts on flame propagation and blast waves of obstacles representing towers, tanks, and various structures inside a chemical plant.

For research on combustion-supporting gases (gases such as oxygen that promote the burning of flammable substances), we

are assessing the combustion properties of various gases of this type, such as nitrogen trifluoride, which has been a cause of accidents in the past, and are working to establish a standard for categorizing the dangers of combustion-supporting gases.

While difluoromethane (R32) and other next-generation refrigerants hold the potential to greatly mitigate the problems of ozone layer depletion and global warming, they exhibit a slightly flammable property. To assess the danger of such refrigerants with slight flammability, we are carrying out combustion characteristics tests and other tests using a large 1 m diameter combustion test vessel that can even evaluate slightly flammable refrigerants with slow burning rate.

Toward the realization of a hydrogen society

With the goal of constructing a network of pipes that supply hydrogen to ordinary households in a hydrogen society, as is currently the case for urban gas supplies, we assessed the leakage of hydrogen from low-pressure pipes, its diffusion behavior, the explosion impact in the event of ignition of leaked hydrogen, and so on through experiments, and provided the basic data needed for gas companies to study possible measures that could be taken in the case of an accident. Since newly laid pipes are filled with air, we also conducted an experimental study on a technique for safely replacing this air with hydrogen without creating a flammable atmosphere containing both hydrogen and air, and are making available the basic data required to create a technical standard for pipeline construction.

We are also conducting various research activities with the aim of increasing the social acceptability of hydrogen stations that are being constructed to meet the expected wide popularization of fuel cell vehicles by 2015. These activities include research aimed at estimating damage through numerical simulation if an unfortunate accident should occur and then quantitatively indicating the risk mitigation effects of safety measures; research to propose safe management guidelines that are intended to prevent accidents arising from human error, poor management, etc.; and research to promote changes in the image of risk through social acceptance surveys formulated based on the results of quantitative assessments of fire and explosion risks, human health risks, and global warming risks.

Part of the work introduced here is the product of a project commissioned by METI and a project recommissioned by NEDO.

Industrial Safety and
Physical Risk Analysis Group, RISS
Yuji WADA

Reference
[1] Saburi, T. *et al.*: *Proc. of the 7th Intl. Seminar on Fire & Explosion Hazards,* 330-339 (2013).

Sustainability Assessment of Biomass Energy Utilization

Concerns about and expectations for biomass energy

It can be regarded that the carbon dioxide released by combustion of biomass resources is offset by its absorption through photosynthesis. Biomass energy therefore has the carbon-neutral characteristic that does not increase the amount of carbon dioxide in the atmosphere, and is considered as one of the energy sources that contribute to greenhouse gas mitigation. At the same time, some positive socio-economic impacts such as economic stimulation on related industries and generation of employment are expected through the development of biomass energy.

On the other hand, there are concerns that a rapid increase in the use of biomass resources may have various negative impacts including loss of

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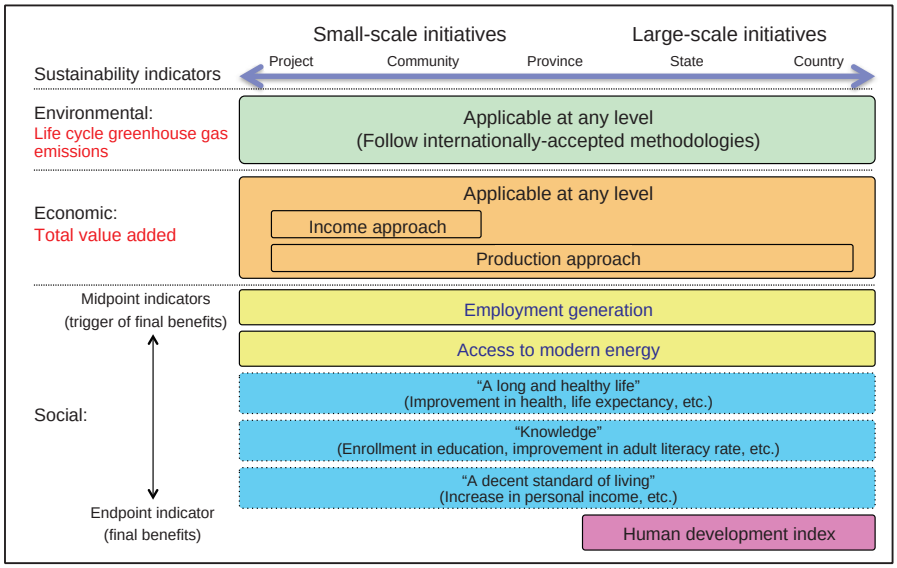
biodiversity, deforestation, depletion of water resources, inappropriate exploitation of land, and competition with food production. In order to utilize biomass energy towards the future in a sustainable manner, the importance for assessments of the impacts, both positive and negative, of biomass utilization from the environmental, economic and social pillars is globally recognized.

Development of a sustainability assessment methodology

Although there is high biomass energy potential in East Asia, most of the countries in this region are heavily dependent on fossil fuel imports to meet their energy needs. It is expected that the biomass energy utilization should play an important role for the future economic growth in this region, and the ideal form of utilizing biomass energy in a sustainable manner has emerged at the forefront.

Since 2007, RISS and researchers from various East Asian countries have been collaborating to develop a methodology that can assess the sustainability of biomass energy utilization suitable for East Asian countries from the environmental, economic and social pillars of sustainability. Our methodology comprises life cycle greenhouse gas emissions as an environmental indicator; total value added as an economic indicator; employment generation, access to modern energy and human development index (an index proposed by the United Nations Development Programme to measure the level of human development that is determined by life expectancy at birth, literacy rate, gross enrollment rate, and gross domestic product per capita) as social indicators.



Indicators to assess the sustainability of biomass energy utilization suitable for East Asia
Based on data availability, evaluation methodology and its indicators under environmental, economic and social pillars are provided according to the scale of the initiatives.

The way forward

The results of the sustainability assessment of biomass energy utilization using the methodology developed will help the decision makers decide whether to proceed with or continue the biomass initiatives or not. In addition, the indicators of our methodology can also be applied to the sustainability assessment of small-scale decentralized renewable energy resources such as solar photovoltaics, wind, small- and pico-hydros, which are expected to play an important role in rural electrification in East Asia. Since 2013, we have thus been expanding our research to the development of sustainability assessment methodology for renewable energy resources suitable for East Asia.

The outcome of this research was obtained through a project commissioned by the Economic Research Institute for ASEAN and East Asia (ERIA).

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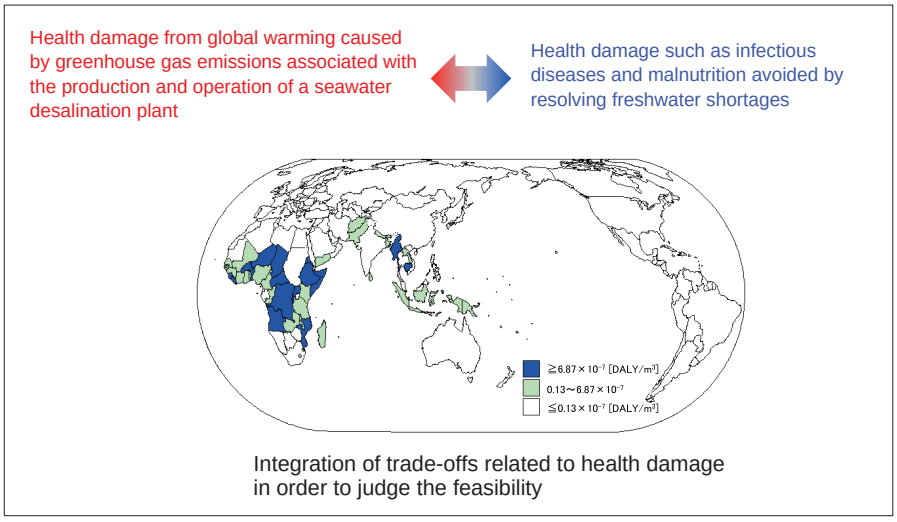
Water Footprint
— Visualization of the hidden environmental impacts of water use —

Water resource issues receiving new attention when introducing technologies or systems

Environmental changes caused by the introduction of a technology or system involve a wide range of environmental issues rather than just one problem, such as global warming or resource consumption. In some cases, multiple effects involving various environmental issues may create a situation in which one effect becomes incompatible with another effect (a trade-off). RISS has been developing methods for assessing broad impacts with respect to a wide range of environmental issues. On the other hand, there are also emerging environmental issues that are expected to be quantitatively assessed anew due to changes in the targets of societal concerns. One of such issues is the scarcity of freshwater resources. Especially in the emerging and developing countries, the demand for fresh water is rising with the increase in population and economic growth of those countries despite their limited amount of available freshwater resources, and the impacts of water resource consumption are becoming a matter of concern.



Example of a trade-off assessment on human health damage to judge the feasibility of introducing a seawater desalination plant
The areas shaded in blue are suitable land. Higher numerical values indicate greater merit.

Consideration for regional differences and global-scale assessment

Freshwater resources exist disproportionately in terms of regional location, and the severity of freshwater shortages as seen in the balance of the amounts of available water resources and demand differs from region to region. Nowadays, raw materials and parts are produced in various regions and countries of the world and the impacts of technologies and systems are felt in wide regions and countries in the world through life cycle of products (from the stage of production of raw materials through to the use and disposal stages) in addition to the production sites of final products. An analytical approach to visualize the hidden environmental impacts arising from the use of fresh water throughout the life cycle of these technologies and systems by assigning them a numerical value is currently attracting attention as a “water footprint.” The international standard for the analysis has also being published in August, 2014.

When assessing the environmental impacts associated with consumption of fresh water, it is essential to establish a model that can assess the impacts on a global scale by considering regional differences like the balance of supply and demand for water and the social and environmental conditions. Focusing on human health damage (infectious diseases due to scarcity of safe water and malnutrition due to agricultural food shortages) attributed to consumption of fresh water, we developed an assessment model of human health damage due to consumption of fresh water on a global scale with the consideration of regional characteristics (the situation of water use, meteorological conditions, availability of medical care, nutritional status, relationships with other countries as observed through food trade and so on).

For inquiries about this article : Research Institute of Science for Safety and Sustainability (RISS) http://www.aist-riss.jp/main/?ml_lang=en

By combining this model with models for the assessment of other environmental issues (global warming, etc.), we will, for example, be able to assess the trade-off relevant to the introduction of a seawater desalination plant between health damage caused by greenhouse gas emissions resulting from fossil energy consumption and health problems avoided by cancellingresolving freshwater shortages (see figure). As shown here, the newly developed model can be expected to promote the assessment of the trade-off impacts relevant to technologies and systems.

Future plans

To further improve the assessment model, we are focusing on the development of a model that can assess the impacts on terrestrial and aquatic ecosystems for more comprehensive assessment of the impacts associated with freshwater use.

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Masaharu MOTOSHITA

Research Hotline

UPDATE FROM THE CUTTING EDGE

Jul.-Sep. 2014

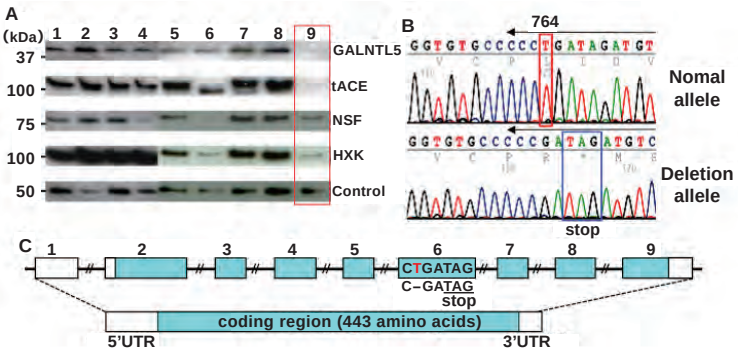
The abstracts of the recent research information appearing in Vol.14 No.7-9 of "AIST TODAY" are introduced here, classified by research areas. For inquiry about the full article, please contact the author via e-mail.

Life Science and Biotechnology

Discovery of gene that causes asthenozoospermia

A technology expected to assist selection of appropriate infertility treatment in the near future

We have discovered many new glycosyltransferase genes from the human genome and have elucidated the in vivo functions of the individual glycosyltransferase genes and their relationships to various disorders. *GALNTL5* was one of the discoveries; however, its function had been unclear for ten years due to lack of the enzyme activity as a glycosyltransferase. As mice have a gene homologous to human *GALNTL5*, the study was conducted on mice with mutated *Galntl5* gene aiming to identify the in vivo functions of the GALNTL5 protein. It was found that heterozygous *Galntl5*-deficient male mice become infertile with symptoms similar to human asthenozoospermia, and that this gene is essential for normal spermatogenesis. A patient diagnosed with asthenozoospermia, one of the causes of male infertility, has been found with a mutation of the *GALNTL5* gene. These results will contribute to the development of methods to judge precisely the cause of male infertility.



A case of human GALNTL5 mutation in asthenozoospermia patients

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AIST TODAY Vol.14 No.7 p.10 (2014)

Testing the safety of transplanting cells using cell culture supernatants

Improve the safety of regenerative medicine

We have developed a noninvasive and quantitative method to detect tumorigenic human pluripotent stem cells using cell culture supernatants. We established a sandwich assay system to detect the soluble hyperglycosylated podocalyxin secreted specifically from human pluripotent stem cells into cell culture supernatants. The sandwich assay utilizes two lectins by focusing on characteristic glycan structures displayed on the soluble podocalyxin: a recombinant rBC2LCN (*N*-terminal domain of BC2-L lectin derived from *Burkholderia cenocepacia*) highly specific to human pluripotent stem cells is used as a "discriminator" to capture the soluble hyperglycosylated podocalyxin. rABA (recombinant *Agaricus bisporus* lectin), an *O*-glycan-binding lectin, is used as a "signal enhancer", which detects *O*-glycans heavily displayed on podocalyxin. The developed system allows rapid diagnosis (<3 h) of a large number of samples using only a drop (50 µL) of cell culture supernatants. The developed method should increase the safety of human pluripotent stem cell-based cell therapies.

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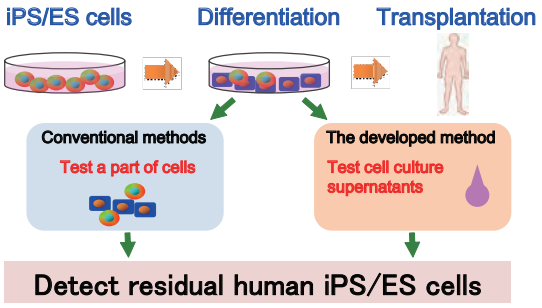
AIST TODAY Vol.14 No.8 p.15 (2014)



Detect residual human iPS/ES cells using cell culture supernatants

Development of high-performance lead-free piezoelectric ceramic

A step toward the practical use of lead-free piezoelectric sensors

Piezoelectric materials are unique in that they can convert mechanical energy to electrical energy and vice versa. They can be used as sensors and actuators. Their applications range widely, from leading-edge electronic devices (fine-movement stages of semiconductor exposure apparatus, precise adjustment mechanism for scanning-type probe microscopes, etc.) to general-purpose electronic devices (inkjet printer heads, image stabilization elements of digital cameras, etc.). As such, piezoelectric materials have become essential to our lives. Presently, lead-based piezoelectric ceramics $Pb(Zr,Ti)O_3$(PZT), which is harmful to human health and the environment, has been used for electronic devices because of lack of lead-free piezoelectric ceramics that can substitute it. Thus, the development of lead-free piezoelectric ceramics has become a global issue. We have succeeded in developing lead-free piezoelectric ceramics with properties comparable to PZT. Their usability has been confirmed via prototyped devices (e.g. AE sensor, ultrasonic distance sensor).

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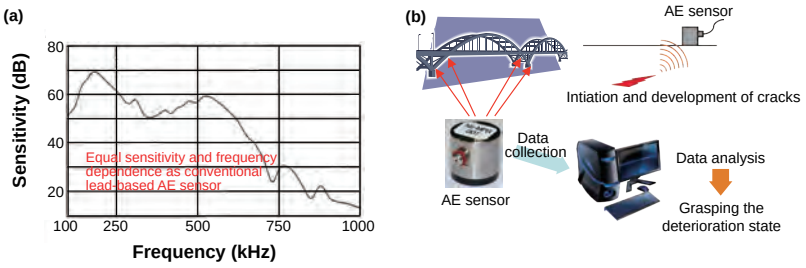

(a) Sensitivity of lead-free AE sensor to the frequency of mechanical vibration
(b) Image of structural health monitoring with AE sensors
The developed lead-free AE sensor was designed to have maximum sensitivity to a frequency of approximately 150 kHz.

Development of highly stable spin torque oscillators

Nanometer-scale microwave generator capable of implementing in LSI or wireless communication device

We have developed highly stable spin torque oscillators (STOs) using nanocontact-shaped magnetic tunnel junctions (MTJs). Our first demonstration of high-power STOs using nanopillar-shaped MTJs in 2008 unfortunately ended up with unstable oscillation frequency caused by the non-uniform precession of the in-plane magnetizations. The present study proposes a newly developed nanocontact-shaped MTJ with improved performance, uniquely suitable for STO. We applied a magnetic field along the out-of-plane direction of the surface inducing a stable out-of-plane precession in the STO. A very narrow spectrum with a high $f/\Delta f$ (f: oscillation peak frequency, ~10 GHz, Δf: peak width) value of over 3000 was achieved while maintaining a high emission power. Incorporating unique features, such as small size, auto-oscillative character without the need of a resonator, and high frequency tunability, the newly developed STO will be a potential candidate for nanometer-scale microwave generators in LSIs and communication devices as well as highly sensitive magnetic field sensors.

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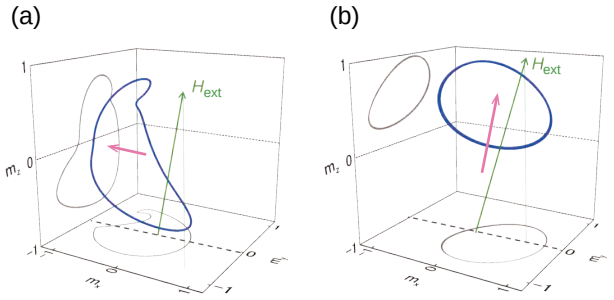

Simulated trajectories during magnetization precession
Blue line represents the trajectory of the magnetization vector during the precession. The green arrow indicates the external magnetic field (H_{ext}) direction and the pink arrow the center axis of the precession. When H_{ext} was small (1 kOe, Fig. (a)), the precession center remained in the in-plane direction, resulting in a distorted trajectory and caused fluctuation in the oscillation frequency. When H_{ext} was large (8 kOe, Fig. (b)), on the other hand, the precession axis aligned parallel to H_{ext}, yielding a circular trajectory with which a highly stable oscillation frequency was obtained. Copyright (2014) The Japan Society of Applied Physics.

Micro-patternable CNT-Cu composite material

High current density tolerance of such CNT-Cu composite wiring, enabling applications in microelectronics

Rapidly evolving architectural and functional complexity of electrical devices has resulted in increasing currents flowing through narrow conducting channels. This has resulted in increased susceptibility to failure of these conducting lines, mainly made of copper (Cu), due to their inability to handle high current density. This created a demand for a material with high electrical conductivity and high current-carrying-capacity (ampacity). To this end, we report micro-fabricated structures made from super-growth single walled carbon nanotubes (CNT) and Cu, capable of withstanding up to 100 times higher current density (600×10^6 A/cm^2) than pure Cu (6×10^6 A/cm^2). We demonstrate exhaustive micro-scale patternability of the CNT-Cu composite material into arbitrary two- and three-dimensional shapes resembling wires, inter-connects, junctions and arrays. The methodology adopted for achieving this is compatible with conventional lithographic techniques, ensuring their facile integration into existing devices and technologies, and targeting practical applications in micro- and nano-electronics.

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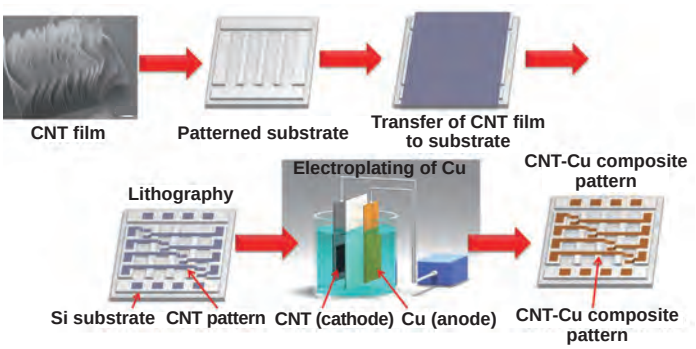

Fabrication protocol of the CNT-Cu composite

Selective synthesis of semiconductor-type single-walled carbon nanotubes

High selectivity (98 %) achieved

A novel method to synthesize the single-walled carbon nanotubes (SWNTs) of semiconductor-type is reported. Selective synthesis of semiconductor-SWNTs was realized by exposing iron catalysts to gas ambient containing small amount of H_2O just before SWNT growth. Raman spectra of the as-grown SWNT films have suggested the preferential growth of semiconducting SWNTs with small diameter of 0.8-1.2 nm range. Importantly, high selectivity was only achieved when the yield of CNTs was low, suggesting that selective growth can be achieved by adjusting the catalyst activity. High performance of a field effect transistor (FET) device was achieved by using an as-grown SWNT film as the channel of FET, where high on/off ratio (> 10,000) and mobility (c.a. 17 cm^2/Vs) at a relatively short channel length (5 μm) were indicated. These characteristics show that the approach of selective growth can greatly contribute to widespread electronics application, such as in flexible electronics devices.

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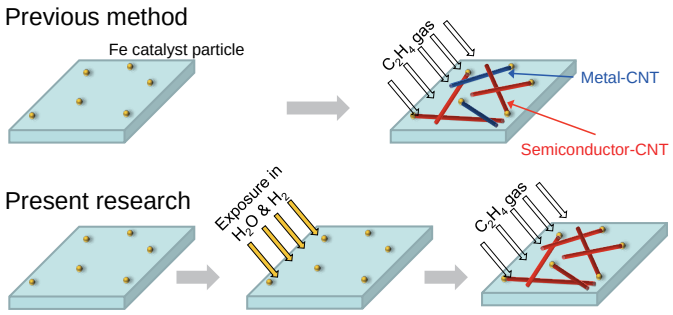

Schematically represented process of the selective growth of semiconductor-type SWNTs

200 mm wafer process for piezoelectric MEMS devices

Practical level piezoelectric constant (-d_{31}>105 pm/V) achieved by pulse poling

We have developed a 200 mm PZT wafer process for piezoelectric MEMS devices. Optimization of the PZT thin film deposition atmosphere and the thermal treatment condition has reduced the number of coarse particles formed on the surface of the PZT thin films, which leads to higher yield rate. We have fabricated piezoelectric MEMS devices from the 200 mm wafer. Pulse poling has resulted in a high piezoelectric constant d_{31} as high as -105 pm/V, where it takes less than 1 second for poling each of the piezoelectric MEMS devices.

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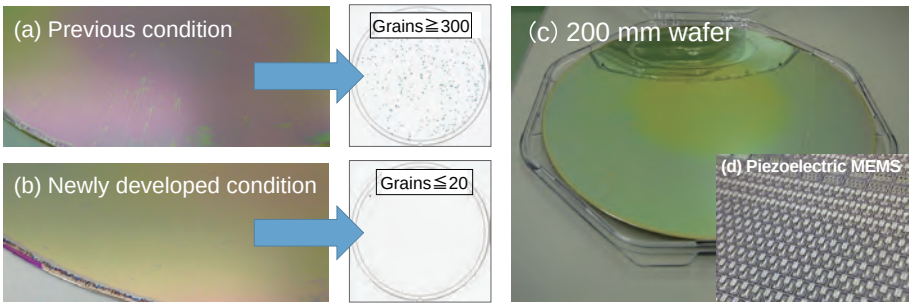

(a) Surface of a PZT thin film deposited under previous condition
(b) Surface of a PZT thin films deposited under the newly developed condition
(c,d) 200 mm wafer after PZT deposition and after piezoelectric MEMS fabrication process

Development of quick and precise measurement technique for evaluation of fracture resistance of ceramics

Reproducible crack length measurement for the indentation fracture method by visualizing the tips of the cracks

We have developed a noble measurement technique for precise and quick evaluation of fracture resistance of ceramics. In the developed technique, a visualizing solution is applied on the indented surface of ceramic test pieces during fracture resistance testing by the indentation fracture (IF) method. The concentration of a commercially available solution was optimized and the solution was diluted to produce the visualizing solution. This could enhance the contrast of the image of the crack tips, reducing errors in reading crack lengths. Measurements of fracture resistance of ceramics by the IF method will become accurate and reproducible since it uses crack lengths for the calculation. The developed reliable technique enables the qualitative assessment of performance of tiny advanced ceramic products and will contribute to the increase of Japan's global market share of ceramic products.

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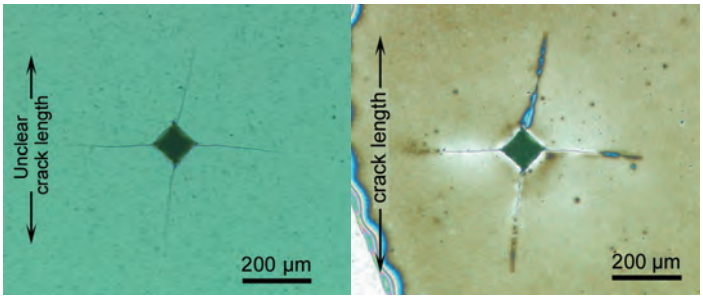

Metallurgical microscope images of an indentation on a surface of ceramic sample
The faint image of crack tips observed with the conventional method (left) became clear and visible enough to measure the crack lengths by the developed method (right).

Development of ultra-compact fluorescence detection module for microfluidic biochemical diagnosis

Key technology enabling rapid near patient diagnosis at home or bedside

We have developed an ultra-compact fluorescence detection module that coaxially configures an excitation source and a detector. A surface emitting micro LED is used as an excitation source. An optical interference filter is integrated with an a-Si:H photodiode, making a fluorescence detector. Light from the surface emitting LED is focused into a spot smaller than the micro-channel width, using an aspherical micro-lens, achieving low-scattering irradiation onto the microchannel. Furthermore, immunoassays can be carried out by combining the ultra-compact fluorescence detection module with a microfluidic chip that has micro-beads packed and immobilized in a microchannel.

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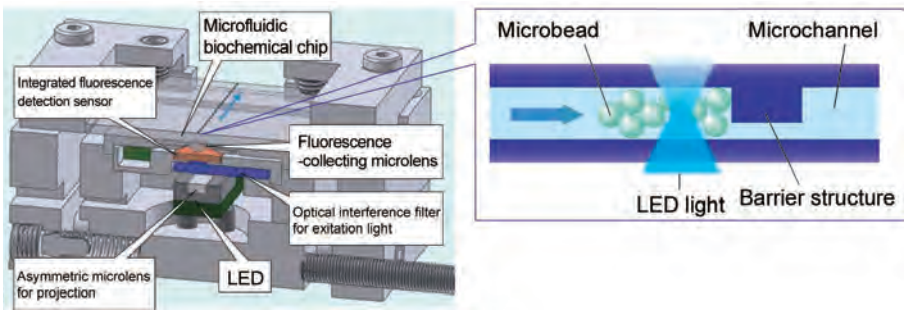

A structural drawing of an LED-induced fluorescence detection module and a cross-sectional view of a microchannel along its fluidic flow

Fundamental measurement technology to support quantum communication and precise optical measurement

Direct observation of ultra-broadband squeezed light with photon number resolving detector

The broad band light sources are expected to realize high-capacity optical communication, optical coherence tomography, optical spectroscopy, and quantum metrology. Squeezed light is a candidate that may serve as a quantum counterpart, however its detection and non-classical characterization at the telecom band have been challenging tasks. Here we demonstrate the direct detection of photon number distribution of the squeezed light with a high efficiency photon number resolving detector (PNRD). The PNRD is based on transition edge sensors with titanium/gold bi-layered superconducting films, which are embedded in an optical absorption cavity. High efficiency of 90 % at the telecom wavelengths and a fast response time of 200 ns are possible. We have directly observed the squeezed light with the PNRD, and have confirmed that the even-photon number distribution is spreading in wide wavelength band width up to 100 nm. Our results and techniques open up a new possibility to characterize non-classical light sources for quantum communication technology.

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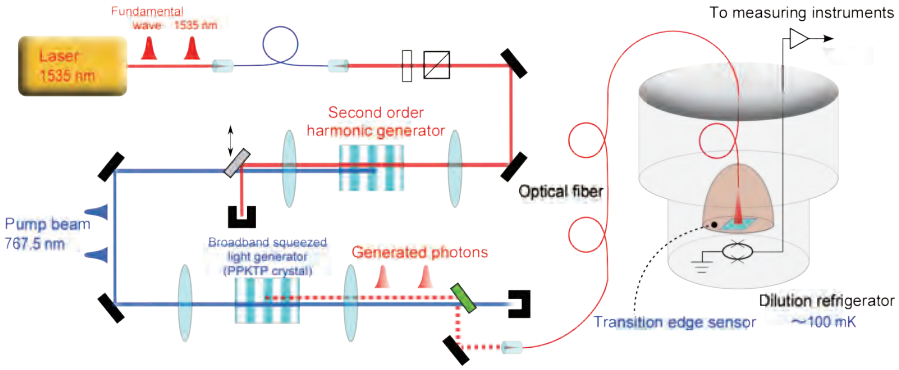

Experimental setup for direct photon number distribution observation of squeezed light

Rapid extraction of radiocesium dissolved in water

Nonwoven fabric cartridge filters impregnated with potassium zinc ferrocyanide

We have developed a cartridge filter including a nonwoven fabric impregnated with potassium zinc ferrocyanide for effectively collecting dissolved radiocesium in water. Experiments with ^{137}Cs concentration conditioned water showed that the cartridge filter could absorb more than 96 % of dissolved ^{137}Cs from the 20 L water at a 2.5 L/min flow rate, and the recovery efficiency did not deteriorate under 3-10 of pH value condition. Measurement test of ^{137}Cs radioactivity concentration in river water indicated that the cartridge filter could apply to natural water monitoring because the detected ^{137}Cs radioactivity by the cartridge filter agreed with that by evaporative concentration within the counting error of the detector.

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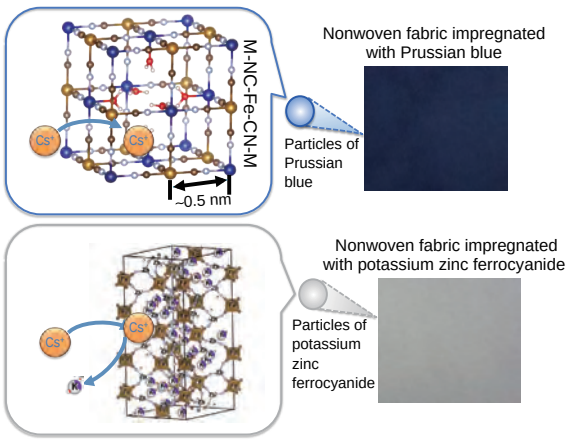
Nonwoven fabric cartridge filter impregnated with potassium zinc ferrocyanide



Adsorption mechanism of the cesium to Prussian blue (upper) and potassium zinc ferrocyanide (lower)

Participation in the Innovation, Science and Technology Cooperation between ASEAN-Japan Workshop

The Innovation, Science and Technology Cooperation between ASEAN-Japan Workshop, co-organized by the STS (Science and Technology in Society) *forum*, A*STAR (Agency for Science, Technology and Research) of Singapore, and JETRO (Japan External Trade Organization), was held at Fusionopolis in Singapore on May 16, 2014.

Dr. Ryoji Chubachi, President of AIST, participated in the workshop, giving a speech, "The Regional Status and World Vision on Innovation," in which he introduced examples of AIST's world class innovation created through collaboration with ASEAN from the viewpoint of green and life innovations. In terms of green innovation, networks with overseas institutions with FREA (Fukushima Renewable Energy Institute of AIST) at the core, as well as collaborations with Thailand, Malaysia, Indonesia, Vietnam, and Singapore aimed at the standardization and wide-spread utilization of biomass energy were introduced. For life innovation, collaboration with Indonesia on the development of natural rubber production technologies was introduced as an example of the development of new materials utilizing biotechnology.

Furthermore, in his speech, Dr. Chubachi commented on the importance of promoting human resource exchange and brain circulation among Asian research institutes in order to make the establishment of AEC (ASEAN Economic Community) a multi-layered undertaking, and also stated that AIST is striving more than ever to accelerate human resource mobility.

From Japan, Dr. Katase, Director-General of the Industrial Science and Technology Policy and Environment Bureau, Ministry of Economy, Trade and Industry, and Dr. Nakamura, President of JST (Japan Science and Technology Agency), were present at this workshop. From overseas, Mr. Lim Chuan Poh, Chairman of A*STAR, and Dr. Marzan Aziz Iskandar, Chairman of BPPT (the Agency for the Assessment and Application of Technology, Indonesia), joined the workshop. The presentations of AIST's activities at the workshop related to the global-scale STS *forum* is expected to lead to the expansion of the international network of AIST.

(Reference) STS *forum* is a global-scale forum held annually in Kyoto in October, which more than 1,000 leaders from all over the world of wide-ranging areas, such as research institutions, governmental organizations, and the economic world attend.

The workshop in progress

Visit by Asia's Highly Talented Young Persons under the SAKURA Exchange Program in Science

Japan-Asia Youth Exchange Program in Science (SAKURA Exchange Program in Science) was started by JST (Japan Science and Technology Agency) in FY2014 to invite to Japan young persons with the potential of playing prominent roles in the future of Asia where dramatic development is underway. The plan aims to foster interest in Japan's cutting-edge science and technology, and to contribute to the cultivation of highly competent human resources.

As part of these activities, 15 persons including undergraduates, graduate students, and professors from the University of Macau of China visited AIST Tsukuba on July 31, 2014. After an overview presentation of AIST, and tours of Science Square Tsukuba and the Geological Museum, a lecture on the utilization technology of Landsat images was given by Dr. Toshiaki Iwata, Chief Senior Researcher of the Information Technology Research Institute. Active discussions followed, as there were many participants from the information technology field.

Moreover, 70 highly talented high school students from China, and another 120 students from ASEAN countries, South Korea, and Mongolia visited AIST Tsukuba on July 31 and August 7, respectively. During their one-week stay in Japan with a busy schedule including lectures of Nobel Prize laureates, visits to research institutes and universities, and cultural exchanges with Japanese high school students, they also visited AIST as a representative research institute of Japan. After an overview presentation of AIST, they visited Science Square Tsukuba and the Geological Museum. At Science Square Tsukuba, robots were very popular, while at the Geological Museum, Dr. Toshimitsu, the Director, gave a lecture on the mechanism of earthquakes and so forth. Since they were highly talented students selected from each country, there were many questions, such as on how to find a suitable university in Japan for robotics research, and on how someone from abroad can become a researcher at AIST.

Chief Senior Researcher Iwata (front row center) and students from the University of Macau

High school students from China (in front of the Geological Museum)

Senior Researcher Katherine Bagarinao, from the Philippines explaining how she became an AIST researcher to students from ASEAN countries, South Korea, and Mongolia.

Discussion in progress

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