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– Self-reform: Road to Rebirth

The 8th Briefing Session of the Japan Atomic Energy Agency (JAEA) was held in Tokyo on November 26th. The previous issue described reform efforts by the JAEA, under the title "Determination for Reform." This issue will focus on research and development results—in particular recent topics, R&D to promote reactor decommissioning, and R&D on responses to environmental contamination.

Report on R&D results

Applications of Spintronics to Nuclear Power

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PDF of presentation: http://www.jaea.go.jp/news/symposium/jaea-houkoku8/report/03-1.pdf
For more information on the lecture content and a video, please see the item "Applications of Spintronics to Nuclear Power" at http://www.jaea.go.jp/news/symposium/jaea-houkoku8/top.html

"Battling with heat"

The Advanced Science Research Center is conducting research with an eye towards nuclear power 10 or 20 years into the future. In this area, heat is a central focus of our research. Today, I would like to give an overview of those efforts.

Electronics uses electricity. When electricity flows, it produces Joule heat. To remove this heat, the K supercomputer requires a cooling facility about the same size as the computer itself. How to overcome and utilize heat is a key issue for the 21st century. Spintronics is a technology for the ultimate energy-saving devices, which do not produce heat, and is attracting attention as a solution to the problem of heat generated by computers.

Now, what is spintronics?

Electrons have two properties: electrical charge, which is the basis of electricity, and spin, which is the basis of magnetism. Conventional electronics uses the charge part, i.e., the electrical part. Spintronics uses the magnetic part, i.e., the spin part.

Directions of spin axes of electrons are random. However, if they are aligned, a magnet is made and electricity flows. Since there is no flow of charge with this spin current, joule heat is not produced. In addition, electric current and spin current can be inter-converted by using a property of heavy atoms called "spin orbit interaction."

Ordinary electronic devices use electron charge. Radiation—due to its ionizing properties—produces charge in circuits (and other objects), and thus is often called "ionizing radiation." As a result, at locations with intense radiation, it is impossible to use ordinary electronic devices employing charge, and, in outer space, malfunction of electronics due to radiation is a major problem. Malfunctions also occur due to traces of radioactive substances contained in the materials of semiconductor devices. Spintronics, in contrast, has the distinctive feature of being resistant to radiation.

Spin current can be produced by employing the microwaves used in microwave ovens or MRI systems in hospitals, and we have succeeded in transporting thermal energy carried by this spin current.

This led to the idea that spin current may be produced conversely using a heat flow, and the spin current may be able to generate electricity.

In 1821, Seebeck discovered the production of electricity directly from heat. This thermoelectric change is called the "Seebeck effect." However, this effect has not led to major applications. The reason is that when electricity flows due to heat, joule heat occurs, and heat flows together with the electricity so that efficiency is extremely poor.

Therefore, the idea of spintronics was incorporated into this thermoelectric generation, and the result was named the "spin Seebeck effect." In conventional thermoelectric generation, as the contact of metals of two different types has electromotive force, there is a need for thermoelectric elements which integrate such contacts. On the other hand, the spin Seebeck effect we have developed can replace such contacts with thin films. Thin films are flat surfaces. As a result, there is no need for the technology to integrate the contacts, and low-cost generation can be achieved by using a large area of surfaces.

This type of thermoelectric generation has garnered attention recently. The reason is that the system has no moving parts; thus reliability is extremely high, and maintenance is unnecessary. In addition, miniaturization is easy, and the system can be used with a variety of heat sources. It can be used with a 100℃ heat source and a 500℃ heat source. At the same time, it is environmentally friendly because it does not produce CO_2. For these reasons, this technology is being reevaluated all over the world.

Recently attempts have been made to use the system in applications. In NASA space probes, the decay heat of plutonium is utilized by being converted into electricity with a thermoelectric element. This approach can be used, maintenance-free, even in locations with weak sunlight. In addition, progress is being made in R&D to convert the heat of hot springs to electricity, and in the initiative to generate electricity by recovering the waste heat of automobiles.

The conversion efficiency of this thermoelectric generation is currently 10%. Our research goal is to raise that to 20%.

There are some problems with thermoelectric generation. Rare metals are used, so the materials are extremely expensive; generation efficiency is low; and integration is necessary. Therefore, we are exploring the possibility of developing thermoelectric elements with a large flat surface using the aforementioned spin Seebeck effect. This does not require integration, and thus the method has excellent affinity for massive and heavy heat sources such as nuclear power.

Generating electricity using the heat discharged by wastes

On the other hand, heat is produced at various points in the nuclear power generation process. For example, considerable heat is produced from the surface of containers for the vitrified bodies enclosing radioactive wastes. Can electricity be generated from the discharged heat by attaching thermoelectric elements to these containers? One of the interim storage facilities at Rokkasho Village can store 1,440 vitrified bodies. Today, this waste is kept in a safe condition through air cooling, but a simple calculation shows that the facility produces about 2 MWt of heat. If this heat is exploited with currently available thermoelectric elements, then an approximate calculation shows that it should be possible to provide maintenance-free electric power for about 100 households for a few decades.

Furthermore, if the performance of these elements can be improved, then it may be possible to introduce them as a new generation method, different from conventional nuclear reactor turbines. We believe that might enable diversification of power sources, improvement of safety during loss of offsite power, and other benefits.

Also, if the performance of thermoelectric elements improves, it may be possible to use them as a substitute for steam turbines. Perhaps they can be incorporated into nuclear reactor designs. Those are my dreams.

Report on R&D results

Development of International Reference Databases used for Radiation Dosimetry Calculations

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For more information on lecture content and a video, please see the item "Development of International Reference Databases used for Radiation Dosimetry Calculations" at http://www.jaea.go.jp/news/symposium/jaea-houkoku8/top.html

Evaluating doses from radiation exposure

I would like to report on the development of databases used internationally to calculate doses from radiation exposure for evaluating the safety of people. The databases are applicable to all types of radiation, ranging from extremely low-energy radiation enabling radiation therapy at the genetic target level, to extremely high-energy radiation which travels through outer space and arrives at the earth.

To what degree are we exposed to radiation in our daily lives? How do we evaluate dose? The quantities which can be directly measured using radiation measurement equipment are: the intensity of radiation at a location, the concentration of radionuclides in the air, foods and drinks, and the amount of radionuclides in the body. Dose to the human body is evaluated based on such information by using "dose coefficients." To obtain these dose coefficients, interaction between radiation and the human body is calculated via computer simulation for various situations where exposure is a possibility. We have developed three databases: two types of radionuclide databases used to calculate these dose coefficients, and a database of dose coefficients for external exposure.

These reference databases used internationally have been developed by the International Commission on Radiological Protection (ICRP) and the U.S. Society of Nuclear Medicine and Molecular Imaging (SNMMI). In collaboration with the ICRP and SNMMI, we have completed these three databases.

The first is the SNMMI radionuclide database. Worldwide, there are about 33 million cases of diagnostic and therapeutic nuclear medicine procedures every year, and this database is used for evaluating the safety of patients who undergo such diagnosis and therapy. The second is the ICRP radionuclide database published as Publication 107, and the third is the ICRP database of dose coefficients for external exposure published as Publication 116. These databases are essential for protecting the public and radiation workers associated with the use of nuclear energy and radiation, and for protection against environmental radiation such as cosmic rays. These databases have recently been completely revised, based on research of the JAEA.

Now, what sorts of technical issues were involved in developing these new databases?

There were two issues in developing the radionuclide databases. First was an increasing demand for the development of new diagnostic and therapeutic methods in nuclear medicine. Inside the body Auger electrons emitted from radiopharmaceuticals result in highly localized energy deposition in an extremely small volume of nanometer orders. Therefore, by applying this principle and using radiopharmaceuticals which accumulate in cancer cells, it will become possible to perform radiation therapy in which only cancer cells are intensively irradiated. In order to evaluate the effectiveness of such therapy, there has been a need for accurate data on Auger electrons, of which there are a few thousand different energies and intensities, specific to each nuclide.

The second issue was dealing with the new nuclides which are generated in accelerator facilities for carrying out state-of-the-art research. These accelerator facilities produce various types of nuclides due to nuclear spallation reactions. However, in the 1990s, there were no dose coefficients for many nuclides produced through spallation reactions.

To resolve these two issues, we developed a method for calculating energies and intensities of radiations emitted by the nuclear decay and the subsequent atomic process using the ENSDF which is the compilation of nuclear structure data. Based on this method, we carried out detailed calculations of data on all types of radiation, including Auger electrons, for 1,200 radionuclides, and the results were incorporated into a database.

In developing the database of dose coefficients for external exposure, the key issue was establishing a method of dose calculation for high-energy radiation.

In the environment we live in, there is high-energy radiation deriving from cosmic rays. For example, the intensity of cosmic rays at an altitude of 10 km, where aircraft fly, is about 100 times the intensity on the earth's surface. Since people frequently travel in aircraft, it is necessary to beware of exposure to cosmic rays. However, in radiation protection developed primarily for nuclear facilities, there has not been adequate technology for detailed analysis of the interaction between high-energy radiation and the human body.

To resolve this problem, we have developed technology for detailed analysis of the behavior of high-energy radiation in the human body. This was achieved by combining the "PHITS", Particle and Heavy Ion Transport code System, developed under the leadership of the JAEA, and a precise model of the human body created from CT data.

By using such technology, we have established a dose calculation method for all types and energies of radiation, in which we accurately simulated the complex interactions caused in the body by high-energy radiation. This was then applied to development of the dose coefficient database.

Use for managing cosmic ray exposure of aircraft crew

Now I would like to provide a brief overview of use of the three databases.

The first database, i.e., the SNMMI radionuclide database, is comprised entirely of JAEA data. It is used for definition of a generalized scheme for dose evaluation for people undergoing diagnostic and therapeutic nuclear medicine procedures, as developed by SNMMI, and is currently being used internationally.

The second database—the ICRP radionuclide database for radiation protection—is used to calculate the dose coefficients for radionuclides by the ICRP. In the future, the results will be published as a series of ICRP Publications in 10 volumes.

The third ICRP database of dose coefficients for external exposure has greatly expanded the range of radiation types and energies, and allows dose assessment for high-energy radiation such as cosmic rays. By exploiting those characteristics, this database has been incorporated into systems for evaluating doses to cosmic rays (EXPACS developed by the JAEA, and JISCARD developed by the National Institute of Radiological Sciences), and is being used to manage cosmic ray exposure of aircraft crews. In the future the new database will supersede the currently used database, and will be used internationally in various applications such as safety analysis of radiation facilities, shielding calculations, and dose evaluation for environmental radiation.

Finally, I would like to describe future efforts.

First will be efforts to incorporate the 2007 recommendations of ICRP. In 2007, ICRP published new recommendations of basic concepts regarding radiation protection. The databases we have developed support the 2007 recommendations. Currently, the IAEA is making preparations to incorporate these recommendations and databases into international basic safety standards, and as a result many countries are considering their response. During this incorporation process, it will be necessary to review safety standards, laws, regulations, guidelines and other provisions relating to radiation protection. In response, we would like to continue to make a contribution—making maximal use of the technology and experience we have accumulated thus far, actively contributing to the revision of the relevant provisions, and ensuring that our databases become well-established and function properly as part of an internationally shared radiation protection system due to the incorporation of these new recommendations.

Second, and even more important, will be efforts to enable the return home of residents evacuated due to the accident at the Fukushima Daiichi Nuclear Power Station. As evacuated residents are returned home in the future, there will be a need to accurately predict doses, reflecting the living situation of each person, and to take precise radiation protection measures by confirming the predicted doses through radiation monitoring. In this area, we would like to help residents to return home, by making maximal use of the dose evaluation technology we have previously developed, and providing the data necessary for protection measures.

R&D for promoting decommissioning and R&D on responses to environmental contamination

Research and Development for Promoting Decommissioning

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For more information on the lecture content and a video, please see the item "Research and Development for Promoting Decommissioning" at http://www.jaea.go.jp/news/symposium/jaea-houkoku8/top.html

I would like to describe the current situation at the Fukushima Daiichi Nuclear Power Station, and the efforts of the JAEA, in both the past and future, to promote decommissioning of the site.

First, let's look at the current situation at the Fukushima Daiichi Nuclear Power Station. At Unit 1, a building cover has been installed to prevent scattering of radioactive materials. At Unit 3, a building cover is currently being installed. At Unit 4, removal of fuel from the spent fuel pool began in November. The radionuclides in the circulating water used to cool the reactors have been removed with a multi-nuclide removal system and other equipment, and the water is stored in 960 tanks. The amount of stored contaminated water and treated water at this site is increasing by 400 m^3 per day.

Aiming to stabilize conditions by removing fuel and debris

Next, I would like to explain the JAEA's efforts to promote decommissioning of this site.

The top priority issues for promoting decommissioning are removing fuel from spent fuel pools, and stabilizing conditions by removing fuel debris from inside reactors. In order to remove fuel debris, it will be necessary to first inspect and repair the partially damaged containment vessels and suppression chambers, and then carry out removal. A key issue for carrying out this work will be technology for decontaminating inside buildings and removing melted and solidified fuel debris.

Another issue will be dealing with treatment and disposal of radioactive waste. This will involve removal of nuclides from contaminated water to the greatest possible extent, security management of wastes, reduction of the amount of wastes, examination of new concepts for disposal of large amounts of waste, and related approaches from an institutional standpoint. Decommissioning scenarios will also need to be considered. As facilities for establishing the basic technology to resolve these issues, there will be a need to construct buildings for mock-up facilities, and facilities for analysis/research on radioactive materials.

To move in this direction, we have established an organization at the JAEA, and we are making R&D efforts with our entire staff of 250 to promote decommissioning of the Fukushima Daiichi

Nuclear Power Plant.

Next, I would like to report on medium/long-term R&D issues, i.e., R&D for removal of fuel debris, and R&D for treatment and disposal of radioactive wastes.

The contamination situation and dose must be evaluated before we can decontaminate and provide shielding for reactor buildings. However, the level of radiation is high inside the reactor buildings where the accident occurred, and approaching these buildings is difficult. Thus, the JAEA has developed a "gamma camera" which makes γ-rays visible, and used this camera to investigate contamination sites on the operating floor (5th floor) of Unit 2.

In addition, decontamination of floors and walls will be necessary to access reactor buildings. To carry this task out, it will be necessary to accurately ascertain the decontamination situation. As a result of previous investigations, it was found that the majority of the contamination on the floors and walls of buildings of Unit 1 to Unit 3 is limited to the paint surface.

Furthermore, the situation inside the reactors will need to be ascertained in order to remove fuel debris. However, the dose is high in each reactor building, and the situation inside cannot be directly observed. Therefore, the fuel distributions in the plants of Unit 1 to Unit 3 of the Fukushima Daiichi Nuclear Power Station were analyzed using MELCOR—computer code for comprehensive analysis of severe accidents. As a result, it was found to be highly likely that the majority of fuel has been damaged, melted, and dropped onto the head at the bottom of the pressure vessel, or into the containment vessel. In addition, we are considering fabricating test equipment which simulates the lower part of the BWR at actual size, and ascertaining the migration behavior of molten material by dropping simulated material, and molten uranium and metals. We believe the obtained results will be very useful in efforts to promote decommissioning.

On the other hand, we have decided to obtain data through testing using debris from the Three Mile Island (TMI) accident stored at the JAEA, and simulated debris produced under likely condition based on scientific calculations. Currently, we have obtained some data. In addition, it was found, regarding criticality measurement, that when fuel debris is removed by crushing it in water, there is a possibility that the debris will become critical if the amount of uranium is about 2 t.

How shall we deal with large amounts of waste?

Treatment and disposal of radioactive waste is another medium/long-term issue. In this area we are conducting R&D based on the distinguishing features of the waste, such as the adhesion of radionuclides derived from damaged fuel, and the salt content due to seawater. We plan to bring together basic concepts for treatment and disposal in FY2017.

As another urgent issue, we plan to evaluate how contaminated water which has leaked out is diffusing underground, and how effective impermeable walls and sub-drains are as measures to prevent influx of groundwater into reactor turbine buildings. In the port, we are conducting analysis relating to the dynamic state of nuclides in the region surrounded by the bank and silt fence, and based on the measurement results, we have inferred that perhaps a leakage point with high-concentration exists near the intake for Unit 3.

Now, I would like to describe our efforts going forward.

We will develop a research center facility in Fukushima Prefecture in order to establish a foundation of technology for the remote control equipment and analysis/research on radioactive materials necessary for decommissioning the Fukushima Daiichi Nuclear Power Station. A facility for demonstrating remote control equipment will be put in place in the Naraha-Minami Industrial Park. We have begun studies of candidate sites for the facility for analysis/research on radioactive materials.

In addition, the experts engaged in R&D to promote decommissioning come from a wide range of fields—not only nuclear power, but also mechanical engineering, materials, chemistry, physics, electricity/electronics, architecture and civil engineering. In order to recruit outstanding personnel in multiple fields in the years to come, we aim to collaborate with universities and industry, and continue to secure and develop personnel on a Japan-wide basis. Furthermore, it will be crucial to integrate and utilize intelligence from both inside and outside Japan, and we will conduct joint research with universities, develop personnel through OJT with the IRID (International Research Institute for Nuclear Decommissioning), manufacturers, and other organizations, and actively cooperate with overseas research institutions.

R&D to promote reactor decommissioning and R&D on responses to environmental contamination

Research and Development on Responses to Environmental Contamination

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For more information on the lecture content and a video, please see the item "Research and Development on Responses to Environmental Contamination at http://www.jaea.go.jp/news/symposium/jaea-houkoku8/top.html

Investigating the migration of cesium

I would like to provide an overview of research and development on responses to environmental contamination. Key steps for resolving these problems will be: R&D to restore the environment in Fukushima Prefecture, coordination/cooperation with relevant organizations both inside and outside Japan, and the Fukushima Prefectural Center for Environment Creation (tentative name) which is being promoted primarily by Fukushima Prefecture.

First, I would like to give a basic description of R&D to restore the environment in Fukushima Prefecture.

Over 70% of the total area of Fukushima Prefecture is forests. According to the present guidelines from the Ministry of the Environment, decontamination of the forests is to be focused on homes and the 20 m zone around the forest edge, and other areas are not to be decontaminated currently. If this approach is taken, cesium will remain in these forests.

Therefore, we are conducting various studies assuming the possibility that cesium will migrate into rivers, together with forest-soil, pass through dams and reservoirs, and thereby reach estuaries and the ocean. We are developing models to predict migration of cesium based on investigation for each area, connecting these with how radiation doses will change over time and how exposure will be evaluated, and if possible using these approaches to improve decontamination technology.

For example, as a result of the investigation of the forests around the Ogi Dam (located upstream on the Tomioka River), we obtained data showing that in the case of evergreen needle-leaved trees, almost all of the cesium remains in place in a fallen foliage layer called the litter layer, and little has migrated into the soil, while in the case of deciduous trees, not much cesium remains in the litter layer and the most has already migrated into the soil. From these results, which show the situation two years after the accident, it was found that overall more than 90% of the cesium remains within 5 cm of the soil surface layer. In addition, water percolated through soil was investigated in deciduous broad-leafed forests in northern Ibaraki Prefecture, and the results showed that only a tiny amount of cesium in forests migrates through the soil. In short, it is difficult for cesium to migrate from forested regions into the surrounding areas.

Cesium in water at the Ogi Dam was below the detection limit in all cases. However, when the mud deposited at the bottom was investigated, the cesium concentration exceeded 10,000 becquerel/kg. There is a great deal of data indicating that almost all cesium is adsorbed into various types of soil, and the results of this investigation are consistent with that. In addition, when the pond on the campus of Fukushima University were investigated, the dose rates were found to be higher at the parts where water comes in.

With regard to rivers, the five rivers in the Hamadori region in eastern Fukushima Prefecture have been surveyed. Of these, the Ukedo River has exhibited an increasing radiation dose rate as time has passed, and it is evident that cesium is being transported through the river. In this river, dose rate tend to be low in places where water is flowing, and high in sections of the river bank. There is also a tendency for the cesium concentration in soil to decrease at locations where it is easy for seawater to flow in.

Now, what can be predicted for the future? As a result of analyses by using various simulations, it is predicted that, in rivers, the radiation dose rate will rise at locations where soil accumulates. In forests, 0.4% of the deposited cesium per year will migrate. If forests are cleared, they will become waste lands, and, contrary to the intended effect, it will become easier for soil to flow out and cesium to migrate.

Next I would like to explain marine diffusion. When measurements were conducted offshore from Fukushima, the results showed that cesium concentration is high in the coastal zone, and the further away from the shore and the deeper in water it gets, the lower the level of the concentration becomes. It is estimated that 95% of the cesium is located in the coastal zone shallower than 200m.

Next, I would like to describe changes in radiation doses and evaluation of exposure.

Immediately after the accident, the U.S. Department of Energy conducted measurements from aircraft. The results were analyzed through joint research with the JAEA, and the amount of iodine-131 deposited on the ground surface (which was previously unknown in the area around the nuclear power station) was determined based on actual measurements. We believe this provides a basis for detailed evaluation of dose.

In addition, we have placed a large display on the Unix Building in front of Fukushima Station, and are using it to publicize data sent in from public buses in four cities of the prefecture. The data is displayed in real-time, in an easy-to-understand visual form.

When an area to be decontaminated has been determined, the first step is to measure the air dose rate. We have developed a system which can analyze the air dose rate before and after decontamination in three-dimensions, and provide a rough estimate of the decontamination cost, by designating decontamination methods (such as stripping off soil or turf, or cutting some branches). We have just started preparations for having local government personnel use this system.

Next, I would like to describe our ties and cooperation with other organizations both inside and outside Japan.

Among organizations in Japan, we are engaged in joint research and collaboration with the National Institute for Environmental Studies, the National Agriculture and Food Research Organization, the Forestry and Forest Products Research Institute, and various universities. Overseas, we are collaborating with the Scottish Universities Environmental Research Center in the U.K., and the Pacific Northwest National Laboratory in the U.S. In addition, in the fall of this year, we held an international cesium workshop in Fukushima City, where views were exchanged with researchers from five countries. The attendees agreed that problems could not be solved by experts alone, that the mass media, politicians and residents should also be involved, and that wet classification can be effective in addition to incineration for reducing the volume of waste. Clay and natural organic materials were also recognized as important substances for understanding the migration of cesium in the environment.

Finally, I would like to describe our response to the Fukushima Prefectural Center for Environment Creation being promoted primarily by Fukushima Prefecture.

This center will be a facility for measuring radiation and conducting studies and research. The JAEA and National Institute for Environmental Studies will structurally support this center. It is considered that future restoration of the environment will proceed through this facility.

The photo shows a scene of collecting material accumulated at the bottom of a dam

It is difficult for cesium to move through forests

Now I would like to summarize.

The biggest problem we face in restoring the environment in Fukushima is handling the forests which cover 70% of Fukushima Prefecture. Also, there is a problem regarding to what extent we will conduct decontamination of areas such as rivers, dams and reservoirs. If we conduct decontamination unlimitedly, the work will never end, producing a tremendous amount of waste, and progress will not be made with superficial measures. The Ministry of the Environment has issued guidelines regarding forests, but the residents have not completely been satisfied with the decontamination policy. Under these circumstances, we have shown through research on the dynamic state of cesium in the environment, that there is no marked outflow of cesium from forests, and that if measures such as felling trees are carried out to deal with forest contamination, they will actually make it easier for cesium to migrate. This will destroy both the environment and ecosystems.

The maximum potential amount of decontamination waste is 31 million m^3. Incineration is one approach for volume reduction, and we have almost completed modeling of cesium behavior during incineration. We are also working on wet classification. It has been determined that recontamination is generally not a serious issue. A significant amount of data has been gathered regarding the long-term behavior of cesium in the environment.

Finally, we hope to conduct goal-oriented, forward-looking R&D to resolve these issues, while overcoming the problems we currently face, so that residents can live their lives with greater peace of mind. We will actively publicize the obtained results both inside and outside Japan.

Closing Remarks

Yonezo Tsujikura, Executive Vice President, JAEA

Today, we have reported on reform of our organization, efforts to address the situation in Fukushima, and some of our state-of-the-art research—all under the title of " Self-reform: Road to Rebirth."

Reforming an organization amounts to reforming people. I am convinced that paths to regeneration can be opened up if each person recognizes pressing issues as their own, and everyone works together as a team. In addition, we recognize the tremendous importance of our role and responsibility in the task of decommissioning the Fukushima Daiichi Nuclear Power Station, and in restoring the environment of Fukushima Prefecture.

Furthermore, we are conducting advanced quantum beam research, and a broad range of R&D on basic infrastructure which is attracting the attention of experts throughout the world. In the future, we will continue to widely and internationally publicize the results of those efforts.

For a video of this lecture, please see the item "Closing Remarks" at
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