



National Institute of  
Advanced Industrial Science  
and Technology  
**AIST**

# From **AIST** to the Innovative World

2014 | **AIST Stories** No. 3

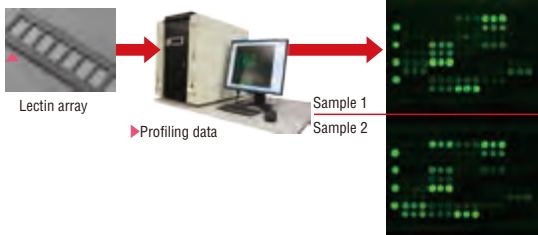
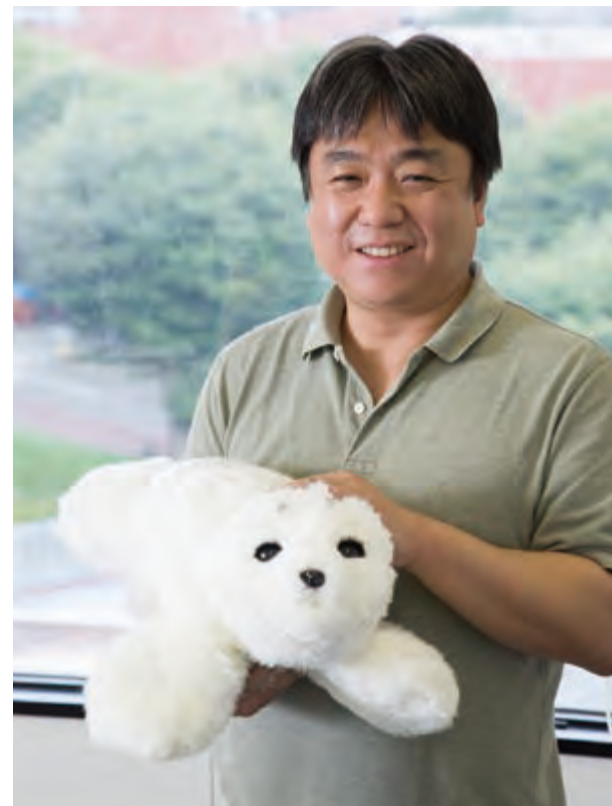
Supporting, changing, and creating the future of life and society



The thin film silicon solar cell – A front-runner in next generation energy

**World-beating power conversion efficiency!  
A solar cell opening the path to the renewable energy future**

**The world's only therapeutic robot  
PARO the robot seal is active in medical treatment and welfare.**



Technology to decipher the glycan – “Face of a cell”

**A glycomarker enables convenient hepatitis testing and diagnosis.**

Identifying risk prior to great earthquake/tsunami occurrence

**The 1100-year old Tohoku tsunami disaster recorded in coastal deposits**



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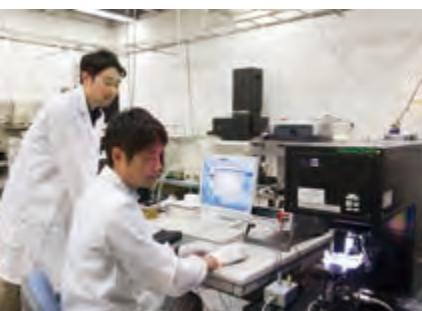
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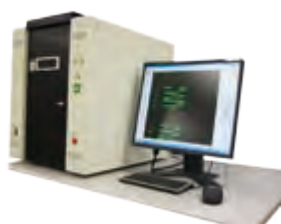
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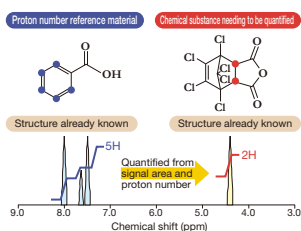
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## On the publication of "From AIST to the Innovative World"

Just what is AIST? Many of you may have this very question. You might have heard of the organization but you have no idea what it actually does. This might apply to many of you. From AIST to the Innovative World is published with the intent of answering such questions for you. We want to communicate the fact that technologies developed by AIST are actually playing roles in your day-to-day activities. Further, the strenuous efforts of AIST researchers to support people's lives and create a better future for everyone are presented.



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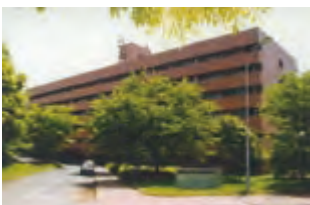


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NAIR – the legendary institute of the 1990s  
Numerous research findings emanating from here affected US nanotechnology policy.

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## The world's only therapeutic robot

# PARO the robot seal is active in medical treatment and welfare

Recognition of effectiveness leads to insurance eligibility from local bodies

**Our life and society will change in this way!**



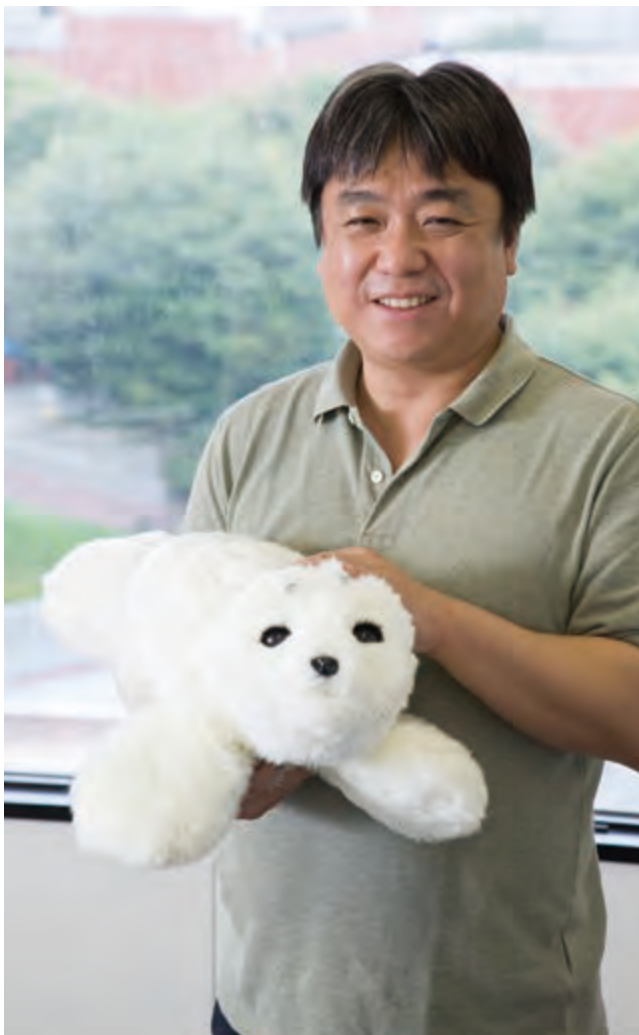
The PARO animal robot can communicate with humans. Long-term clinical trials have shown that by interacting with PARO, depression and anxiety can be controlled, behavioral and psychological symptoms of dementia (BPSD) of patients such as wandering about, violence, and abusive language can be improved, and speech faculty can be recovered. In other words, PARO has shown therapeutic effect for the human heart. The robot's introduction as a medical and welfare device is progressing both in Japan and overseas. If the burden on nursing staff and caregivers can be reduced and the quantity of antipsychotic drugs administered also reduced, this could lead to a long-term reduction in medical and welfare costs.

### A charming robot to communicate with humans

A baby seal with soft white fur and round brown eyes. One feels a definite sense of mass when holding it in one's arms. Stroking the robot brings blinks, flapping of its feet and a seal-like cry.

This is the PARO seal therapeutic robot developed by AIST. Strictly speaking, this is the ninth-generation of PARO. Resembling a harp seal pup, the robot is around 57-cm long, weighs 2.5 kg, and besides being equipped with artificial intelligence, it incorporates ubiquitous surface tactile sensors,<sup>\*1</sup> optical sensors, a posture sensor, temperature sensors, and seven silent actuators for moving the eyelids, neck and legs. The robot's whiskers are also tactile sensors. All of these were independently developed using the most advanced technologies with the participation of more than 80 Japanese companies.

With artificial intelligence being incorporated, repeatedly calling the robot by a specific name means it will eventually remember this name as its own. A behavior learning function is also incorporated, enabling the robot to learn behavior patterns that please the owner when it is touched, thereby becoming a pet that the owner likes. And just like with a real



Chief Senior Researcher,  
Human Technology Research Institute

**Takanori Shibata**



## Terminology at a glance

### PARO, a therapeutic robot

The ninth-generation PARO is 57-cm long and weighs 2.5 kg. “Sense organs” include optical sensors (eyesight), a voice recognition sensor (hearing), and ubiquitous surface tactile sensors (sense of touch). PARO recognizes when it is being gently patted and stroked. The eighth-generation robot actually functioned like a real pet with a biorhythm of morning, daytime and night but the ninth generation therapy robot features enhanced user friendliness and does not sleep, even at night. Besides white, PARO is also available in gold, pink, and charcoal gray.

#### Sense of touch

Ubiquitous surface tactile sensor

#### Actuators

Moves neck, forelegs, hind legs, eyelids

#### Temperature

Temperature sensor

#### Posture

Control via 3-axis acceleration sensor

#### Body surface

Artificial fur reducing bacteria

#### Intelligence

32-bit CPU

#### Hearing

Microphone (three locations)

#### Eyesight

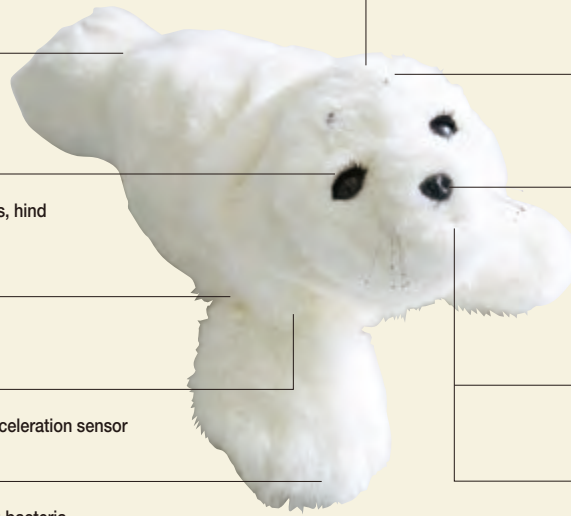
Stereo eyesight sensor (mounted in nose)

#### Charging unit

Pacifier type

#### Voice

Speaker



pet, the owner grows fond of the robot as communication continues. In 2002, PARO was certified as the world’s most therapeutic robot and it was also mentioned in the Guinness Book of Records.

“Even if the PARO is the world’s best, it’s the only therapeutic robot in the world,” laughs Human Technology Research Institute Chief Senior Researcher Takanori Shibata, the inventor of PARO. For the past approximately 20 years since 1993, Shibata has dedicated himself to R&D for PARO, engaging in demonstrations and clinical trials at medical treatment and welfare facilities throughout the world, and training for PARO’s introduction. In recent years, progress has been made with field verification evidence of the “therapeutic effect” of PARO starting to become clearer. Shibata says that more than 3000 PARO robots have already been introduced in around 30 countries.

### I wanted to create a robot that worked from the heart

Speaking of robots, industrial robots normally come to mind so why did you come to develop PARO?

“At the time, I thought of two major directions in which robot research was headed. One was to make industrial robots more intelligent. The other was to come up with new applications for robots. One of the new applications that I thought of was a personal robot that would enter people’s lives and work for them. And when I say ‘working for people,’ I didn’t really mean physical tasks such as cleaning or dishwashing. If this was the case, I think you’d be better off with devices dedicated to these specific tasks such as cleaning robots and dish washing machines. On the other

hand, what I came up with was the idea of creating a robot that did no work.”

Normally, robots are made to serve some type of work function. So is there any potential for robots that do not work? Shibata envisaged the image of a pet for a robot that didn’t work, but nevertheless became an indispensable part of someone’s life. He imagined that there would be people that would like to keep a pet but on account of health or household issues were unable to have one. The scale of interaction between pets and humans was indicated by the very size of the market. The pet market in the US in the early 1990s was valued at JPY4 trillion while it was around JPY1 trillion in Japan. If these markets were to grow at just 1% per annum, this would equate to tens of billions of yen. He thus envisaged that a market indeed existed.

“How about a robot that has the same role of a pet? While I was investigating, I found it was well known in the US and Europe that animal therapy that includes interaction with animals improves the condition of inpatients, the elderly and children alike.”

People become calm when they pat pets; when they speak to pets and get a reaction, they want to communicate even more. The objective of animal therapy is achieving psychological effects, physiological effects such as stress reduction, and social effects such as revitalized communication through coming into contact with a pet.

In advanced economies such as Japan, with the populations aging as people have fewer children, caregiving has become

\*1 **Ubiquitous surface tactile sensor:** A tactile sensor developed for PARO that feels good to the touch and performs well. A sponge is sandwiched between two film electrodes and the strength of touch is measured from the difference of electrical potential. The sensor can distinguish between stroking and patting.



▲ The charger resembles a pacifier. The energy saving design allows the dedicated battery to store enough power for PARO to function for 5–8 hours on a single charge.

a major social issue. Caregiving is more than just providing food, clothing and shelter. It is also important that the people being cared for feel secure and satisfied. Animal therapy is thought to be effective in achieving these aims. Needless to say, therapy is not only directed at the elderly but also patients in hospitals and others including children with developmental problems and the mentally ill.

“However, it is difficult for caregiving facilities to keep animals for reasons such as hygiene, safety and management. Robots might therefore be useful for methods such as animal therapy. Thence, I started to research a robot that would work on the human heart and soothe the mind.”

### A pet robot that can blend into people’s lives

A robot that could take the place of a pet in medical treatment, welfare facilities and households where home care is being undertaken would contribute to making life more pleasant for care recipients. They would feel at ease and enjoy a better quality of life (QOL),<sup>\*2</sup> while at the same time the burden on caregivers and social costs would be reduced. Shibata targeted development of such a robot.

However, while a robot whose role is to manufacture something in a factory should be low-cost, fast, and accurate, a robot that works heart-to-heart should be beautiful, enjoyable and comfortable. The evaluation standards must therefore be subjective. What represents an appropriate robot

for the person that is going to use it? What form should it adopt? Everything started from scratch.

Starting in 1995, Shibata held a concurrent post at the Massachusetts Institute of Technology (MIT) in the US, where he was a research scientist at the Artificial Intelligence Laboratory. Here, he studied the situation at elder care facilities in the US and the extent to which animal therapy was deployed. In addition, while carrying out psychological experiments and fabricating various prototypes of animal-like robots, he completed the first generation prototype of PARO while he was stationed there in 1998.

“Some animals are familiar to us while others are not so familiar. But the animal that I first thought of was a baby seal. The form of a seal seemed attractive when I tried to imagine someone hugging a pet or sitting it on their lap while watching television or talking with other people; however, when it comes to pets, one normally thinks of dogs or cats. Thereupon, I experimented with dog, cat and seal types. For example, while the cat type that I prototyped was an animal that everyone knew and was thus approachable, its standing fell when it actually came into contact with people. Besides being well known, after contact for some time, its body movements and tail wagging ended up being unnatural and different from the real thing; consequently, a sense of unease

\*2 **QOL**: Quality Of Life. An evaluation standard for improvement of people’s life quality. It not only includes material wealth, but also cognitive, emotional and activity factors to provide an overall assessment of life quality.



▲ An elderly person engaging with PARO at a welfare facility

emerged. On the other hand, the seal type is not so familiar so it is harder to compare it with the real thing. It scored a positive assessment as people enjoyed its reactions when touched.”

Through such trial and error, a model of a baby harp seal ended up being made. However, being unfamiliar with the animal, I set off for an island in the northeast of Canada to carry out biological research on the harp seal with the goal of incorporating the cuteness and movements of the real thing into the robot.

## Are seniors with dementia soothed by PARO?

Does PARO really have a soothing effect? In order for objective assessments of this to be possible, with the cooperation of various clinical settings since the first generation model was developed, Shibata has undertaken numerous demonstrations and trials both in Japan and overseas.

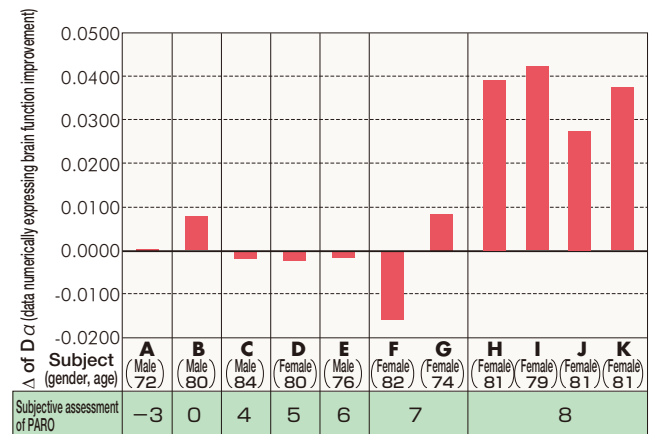
One such example was the calming effect on dementia patients. The core symptoms of dementia are generally considered to be memory impairment and a decline in the ability to comprehend and make judgments but in many cases, behavioral and psychological symptoms of dementia (BPSD) such as depression, irritation and accompanying abusive language and violence emerge as a result of changes in the environment and surroundings. These BPSD translate into a heavy burden on caregivers; if these symptoms could somehow be controlled or mitigated by PARO, one can anticipate major benefits not only for the patients, but also the caregivers.

Furthermore, PARO could also potentially become a common topic of conversation for patients, caregivers and other residents and an opportunity to deepen mutual understanding. Effectiveness in the abovementioned benefits was also tested.

“In summary, use of PARO can produce significant benefits such as reducing stress levels in patients, improving symptoms of depression, reducing patient anxiety and pain, mitigating and suppressing the BPSD, and improving and restoring conversation functions. We were able to present evidence in the form of data reflecting the therapeutic effects of PARO.”

One example was the PARO Project carried out in Denmark

## Relationship between subjective assessment of PARO and improvement in brain function as analyzed by DIMENSION.



Source: AIST press release ([http://www.aist.go.jp/aist\\_j/press\\_release/pr2005/pr20050916/pr20050916.html](http://www.aist.go.jp/aist_j/press_release/pr2005/pr20050916/pr20050916.html))

▲ The vertical axis indicates the delta (difference in value) of  $D\alpha$  before and after interaction with PARO.  $D\alpha$  represents the locational smoothness of the scalp’s electric potential distribution of  $\alpha$  waves. The higher the positive value, the larger the dementia improvement effect is. The horizontal axis shows subjective evaluation levels for PARO. Data was analyzed based on the evaluations of 11 valid respondents. The analysis shows a greater improvement in dementia when PARO’s subjective rating is high.



▲ An inpatient girl at Sweden’s Karolinska Institute Hospital being soothed

between 2006 and 2008 to promote home care solutions for the elderly. A seven-month trial was conducted using 12 PARO robots and other equipment and technology for the home care of elderly dementia sufferers and clinically assessed. The following specific findings were reported.

- An elderly woman suffering from Alzheimer’s disease had trouble communicating with people around her because she spoke in a mix of different languages. However, after caressing PARO and enjoying the interaction, she spontaneously started to speak in easy-to-understand language that was not mixed up.
- A woman who was administered large quantities of sedatives to combat her aggressive reactions returned to a positive, balanced state through caring for PARO and medication was no longer necessary.
- Worried about the household’s dog, a male dementia sufferer was wandering the streets late at night. When PARO was placed beside him when he went to bed, he was able to sleep all night.

## Development history

- 1993** Development of pet robot commenced.
- 1995-1998** Psychological tests were conducted and PARO prototypes were developed at MIT's Artificial Intelligence Laboratory.
- 1998** Second generation featuring improved external appearance and functionality is fabricated at Mechanical Engineering Laboratory (now AIST).
- 1999** The number of actuators is increased from two to seven in the third generation. Appears in the annual end-of-year song contest on Japanese national television. Short-term onsite trials undertaken at medical and welfare facilities.
 
- 2000** Fourth generation with voice recognition function developed. Long-term trials conducted at an isolation ward of a children's hospital after the fifth generation passed ethical review.
- 2001** Sixth generation incorporates independently developed actuators and sensors. Reliability and durability improved.
- 2002** Certified in the Guinness Book of Records as the world's most therapeutic robot.
- 2003** Seventh generation adopts a modular construction with an eye toward commercialization. Clinical trials commence at Japanese and overseas medical treatment and welfare facilities.
- 2004** From the eighth generation, PARO's intellectual property rights are licensed to AIST spinoff Intelligent System Co., Ltd.
- 2005** Exhibited at Expo 2005 Aichi Japan at Government Pavilion and AIST booth, etc.
 

◀ The NEDO booth at Expo 2005 Aichi Japan
- 2006** Field-testing starts in Denmark. This formed the basis for a documentary. Subsequently, full-fledged adoption of PARO starts in Denmark.
- 2009** Certified as a medical device in the US. Sales commence.
- 2009-2010** Seconded to the Cabinet Office. In charge of caregiving robot-related activities.
- 2011** Psychological care through PARO implemented on a continuing basis at evacuation centers and temporary housing projects related to the Great Eastern Japan Earthquake and Tsunami.
- 2013** Ninth generation dedicated to therapy is completed. Kanagawa Prefecture introduces a subsidy (50% contribution) and caregiver training scheme for welfare facilities.
- 2014** Okayama City makes use of PARO eligible for caregiving insurance payments for home care where a caregiver is required. PARO visits the US White House. Japan's Emperor and Empress meet PARO.

Trials showed that people who were lonely, wanted more response from others, and were desperate to care for someone or something had their hearts activated and stimulated by PARO: they felt happier through conversation. A certain level of interaction with PARO was also found to reduce depression and irritation in some people.

“PARO is believed to bring about these effects via better blood flow in the brain, in particular in the prefrontal area that controls feelings and the temporal region that controls speech.”

Based on these findings, more than 70% of the local governments in Denmark formally introduced 300 PARO robots at their facilities for the elderly and implemented an educational and training program for effective utilization of PARO.

In Japan too, smiles returned to the faces of elderly persons that were formerly highly aggressive, people became able to speak spontaneously, wandering in the evening became a thing of the past, and those that previously slept during the daytime stayed awake by playing with PARO. Further, quality of sleep also improved among the various reported cases of symptoms improving.

### All sensors and actuators developed independently

PARO continues to make progress from a hardware aspect. Since the first generation, sensor types and number of actuators employed have been varied in order to improve functionality and the robot has become more lifelike. A modular construction was adopted for the seventh generation with commercialization in mind that took into consideration ease of assembly and maintenance.

The current version of PARO that debuted in September 2013 comes in a pet version and a therapy version. Overall length is 57 cm and based on feedback from clinical trials: weight has been reduced to 2.5 kg. Behavioral patterns were changed to make it easier to enhance therapy effects. Previously, PARO reacted negatively to rough treatment but this was changed to a tolerant character that would not become angry or get in a bad mood if it was hit.

Although an antibacterial material was initially used for the fur to prevent bacterial growth, from an enhanced hygiene and safety perspective, this was changed to an active bacteria-suppressing material that reduced the number of bacteria. Various languages were prepared for the voice recognition software; language could thus be customized depending on the country.

More than anything, PARO is durable. At any rate, PARO is a “pet” and the assumption is that it will be with patients for ten or more years. Although at one event in the past it came into contact with around 1 million people and was ruined, now, its shortcomings have been resolved and it has the



durability to last for many years of play without breaking, even if it is dropped.

## Approved in the US as a “medical device”

Nowadays, moves to adopt PARO as a medical welfare device continue to spread in Japan and throughout the rest of the world. In Germany, for example, healthcare insurance can be applied when PARO is used for visiting therapy in home care. Furthermore, research is underway in the Netherlands as to how to best utilize PARO at medical treatment and welfare facilities.

“PARO was also certified as a medical device in the US after an exhaustive evaluation; introduction has started at Department of Veterans Affairs hospitals and private sector facilities in several states. At present, human resources training is continuing in order that PARO be utilized appropriately. In addition, a three-year clinical trial was conducted in Australia at a cost of JPY100 million; authorities there are currently at the stage of considering introduction into the public health and welfare system.”

All of these countries are of the view that if the burden on caregivers and the quantities of drugs administered can be reduced through introducing PARO, then the social costs born by the country can be reduced. The situation is the same in Japan.

In Japan, Kanagawa Prefecture has been carrying out clinical evaluation of PARO since 2010 and together with a training program; it introduced a subsidy system in fiscal 2013 that reimbursed facilities for half of their costs. Furthermore, the comprehensive community healthcare model area of Nanto City in Toyama Prefecture implemented a monitor study of households requiring caregivers for home care. The study has shown that besides reducing the quantity of sedatives administered at more than half of these households, there were also cases whereby caregiver burden was reduced when other family members were busy and couldn't pay much attention to the elderly person, who was happy to play with PARO. In Okayama City, PARO became eligible for nursing care insurance coverage starting February 2014 and field-testing of PARO application for patients in home care environments is underway. This should lead to wider adoption in the future.

Over the 20 or so years of PARO R&D, PARO has developed to the point where it is an integral part of the social system in Japan and overseas. Incorporating the latest technology, the robot blends into the lives of people, it has been accepted by society, and its use is set to expand. This development is a perfect example of AIST technology being adopted practically under its slogan “Integration through Innovation.” This was the culmination of an unshaken vision that overcame various challenges one-by-one over time.



▲ PARO is used at a US Department of Veteran Affairs Hospital to maintain a favorable state for sufferers of dementia and PTSD.

## The future image of PARO

## A vision of the future

In a society where aging is set to become an increasingly severe problem moving forward, PARO looks set to become increasingly in demand in more and more countries and regions. Social systems, cultures and safety standards vary from country to country; PARO is being improved to account for such differences through listening to the needs of experts onsite. The intent is to more clearly show evidence related to the therapeutic effects in order to expand such opportunities.

Development of PARO will also continue in order to tailor the robot for applications other than dementia, such as for children with developmental problems and the mentally ill. “PARO handlers” will also be trained with the skills required to effectively deploy PARO with the intent of contributing to society through PARO being in a position to please more and more people.



The thin film silicon solar cell – A front-runner in next generation energy

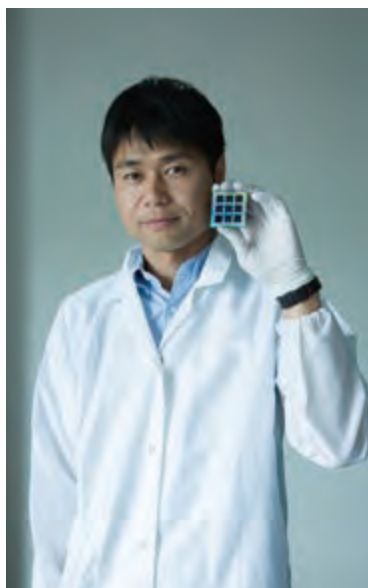
**World-beating power conversion efficiency!**  
**A solar cell opening the path to the renewable energy future**

Resource saving and cost saving will provide impetus for widespread adoption

**Our life and society will change in this way!**

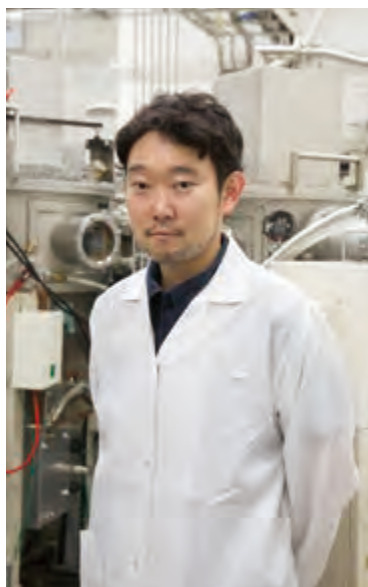


Solar cells convert the energy of sunlight into electricity. And while they have a history of more than 50 years of R&D and are highly anticipated as a next-generation energy source, equipment costs and power generation efficiency are still issues and widespread deployment is taking time. If the power generation efficiency of the thin film silicon solar cell being developed by AIST can be further improved and the cell commercialized with the advantages of low cost and resource conservation, this will give a boost to more widespread use of solar cells and can be expected to contribute greatly to solving current challenges associated with energy.



Senior Researcher, Advanced Low Cost Processing Team, Research Center for Photovoltaic Technologies

**Hitoshi Sai**



Senior Researcher, Advanced Low Cost Processing Team, Research Center for Photovoltaic Technologies

**Takuya Matsui**

**Thin film silicon solar cells hobbled by low power generation efficiency**

The energy from light from the sun that drenches the earth is massive: just one hour's worth of this energy is equivalent to the annual energy consumption of all mankind. Not only is solar energy essentially inexhaustible, no greenhouse gases such as CO<sub>2</sub> are emitted when it is converted into electricity. Further the energy generated by a solar cell far exceeds the energy required to manufacture the solar cell. If this limitless energy source can be used efficiently, it is not an exaggeration to say that Japan's, and indeed the world's energy problems could be solved.

At present, however, almost all sunlight energy incident on the ground and buildings is absorbed, converted to heat, and subsequently escapes into the atmosphere. In other words, hardly any of this energy resource is utilized. The solar cell is the enabler in converting this unused energy into a source of electricity.

Interest in renewable energy in Japan has heightened since the Great East Japan Earthquake and Tsunami of 2011 but in



- Residential
- Safety and security
- Eco products



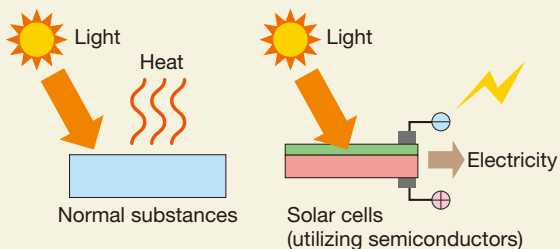
- Environment, resources, energy
- Electronics
- Materials

## Terminology at a glance

### Solar cells

#### ● Principle of solar cells

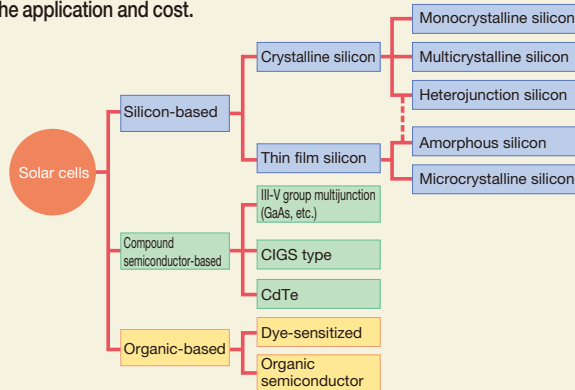
Normally, the energy from sunlight is converted into heat (left). This is why asphalt in mid-summer becomes hot. On the other hand, solar cells absorb sunlight energy and employ semiconductors to convert this to electricity (right). Even though they are referred to as “solar battery” in Japanese, they have no capability to store electricity. Electricity is only generated when light is incident on the cells.



Source: Website of Research Center for Photovoltaic Technologies

#### ● Solar cell classification

The broad classifications in terms of materials are silicon, compound semiconductor and organic. More detailed classification gives as many as several dozen types and which one is adopted depends on the application and cost.



actual fact, the history of research into solar cells is long and the first commercial example of their application was in a satellite launched in the 1950s.

Crude oil prices skyrocketed in the 1970s on account of the first oil crisis; this brought about a strong global interest in power generation based on sunlight. In 1974, the Sunshine Project<sup>\*1</sup> was inaugurated in Japan to promote development of next generation energy.

AIST has been conducting R&D on solar cells (amorphous silicon solar cells) since the 1970s, including work at a predecessor organization (Electrotechnical Laboratory, Agency of Industrial Science and Technology). R&D on various types of solar cells is currently underway at AIST, which is prioritizing green innovation that is compatible with the economy and the environment. Each type has its merits and demerits. Currently, the most widely adopted type is the crystalline silicon solar cell.<sup>\*2</sup> Conversion efficiency is high but production cost is also high. This high cost is a major factor inhibiting more widespread usage of solar cells.

We want to make low cost solar cells using the safe silicon that exists in large quantities in the earth. The thin film silicon solar cell is expected to be able to satisfy these demands. This cell type employs a thin silicon layer of around 1  $\mu\text{m}$  (micrometer,  $\mu\text{m}=10^{-6}$  m) or less in thickness.

“Thin film silicon solar cells are fabricated by forming silicon layers on large glass and plastic substrates. Large-area cells are fabricated and while the process is thus suited to mass production, low power generation efficiency has long been a drawback associated with this type of cell. AIST has participated in consortium research<sup>\*3</sup> since 2010 to solve this problem. As a result, in February 2014, a thin film microcrystalline silicon solar cell<sup>\*4</sup> with a power generation

efficiency of 11%, the best in the world, was realized.”

Hitoshi Sai, Senior Researcher at the Research Center for Photovoltaic Technologies, was in charge of this development.

## Thinner enables resource saving

The overriding important aspect of a solar cell is its power generation efficiency. Absorbing as much sunlight as possible over a small surface area and generating as much electricity as possible leads to higher added value and reduced cost. The current mainstream crystalline silicon solar cell has higher power generation efficiency than other existing types of solar cell (ca. 26% and 15–20% once incorporated into a module); although it is of high quality, the silicon layer is 200  $\mu\text{m}$  thick. This silicon-intensive structure makes it difficult to save

\*1 **Sunshine Project:** A long-term national project inaugurated in July 1974 to carry out R&D into new energy technologies for Japan.

\*2 **Crystalline silicon solar cell:** A solar cell that employs crystalline silicon as a material. The oldest type of cell, accounting for close to 90% of the solar cells in general usage.

\*3 **Consortium research:** Consortium-based R&D related to thin film silicon solar cells that is being undertaken as part of the project, Development of Next-generation High-performance Technology for Photovoltaic Power Generation Systems, started by NEDO in 2010. As of September 2014, participants included the Photovoltaic Power Generation Technology Research Association, AIST, five private-sector companies, and three universities. The Photovoltaic Power Generation Technology Research Association was established in 1990 by 23 companies engaged in the solar cell business; currently, 60 private sector companies are members.

\*4 **Thin film microcrystalline silicon solar cell:** Thin film microcrystalline silicon is a solar cell material that is primarily comprised of silicon and hydrogen atoms. In this material's composite structure, extremely fine silicon crystals are incorporated into an amorphous (non-crystalline) silicon matrix. Power generation is possible from the visible spectrum through to the near infrared spectrum, and there is almost no light-induced degradation.

## Solar cell types and major features

	Conversion efficiency	Material abundance	Flexible solar cell	Scope for cost reduction
Monocrystalline silicon	◎	△	×	△
Multicrystalline silicon	○	△~○	×	○
Thin film silicon	△	◎	◎	◎
Heterojunction silicon	◎	○	×	○
CIGS-type	○	◎	◎	◎
CdTe	△	◎	○	◎
Dye-sensitized	△	◎	△	◎
Organic semiconductor	△	◎	◎	◎
III-V group multijunction	◎◎	△	△	△

Source: Website of Research Center for Photovoltaic Technologies

resources and there are limits to how much cost can be saved. However, if silicon can be formed into a thin film, resource saving and cost saving would become possible. Furthermore, if the film can be made flexible, the application scope could potentially be broadened. An R&D project for thin film silicon solar cells has been pursued through an alliance between the government and private sector companies. Thin film silicon solar cell types include amorphous silicon solar cells<sup>\*5</sup> and microcrystalline silicon solar cells; each have distinct properties. Amorphous silicon solar cells use amorphous (non-crystallized) silicon in the power generation layer and their light absorption coefficients are larger than those of crystalline silicon; they are characterized by their absorption of visible light of relatively short wavelengths. Microcrystalline silicon solar cells use a material comprised of agglomerates of extremely fine silicon crystal grains of less than 1 μm in diameter; they can generate electricity via irradiation from the visible spectrum through to the near infrared spectrum.

“In actual fact, silicon itself is not a good absorber of light. And the thinner it is, the less efficient it becomes. The important point when forming thin films of silicon while at the same time improving absorption is how to trap the light within the thin silicon film. The structure of a thin film silicon solar cell is comprised of a substrate, a silicon film (power generation layer), and electrodes. The thinner the silicon film is, the more sunlight passes directly through the silicon film. Therefore, the substrate surface is made uneven (textured) in order to reflect or scatter light and retain it within the silicon film for as long as possible in order to raise absorption.” (Sai)

### How can light be trapped efficiently?

Senior Researcher Takuya Matsui has been involved with research into thin film amorphous silicon solar cells since joining AIST in 2002. According to him, “Until recently, the textured structure of the substrate surface was generally characterized by random morphology. This was because light is comprised of light of various wavelengths so morphology with various sizes and angles was thought to be more efficient

overall.”

In actual fact, the random texturing method has been used to improve performance up until now. However, in the past few years, this method has started to reach its limits.

“If we continue along the same line as in the past, it will prove difficult to make any more performance gains. Accordingly, we decided to return to the basics and have a rethink. We came to think about what would happen if we made the textured structure regular.” (Sai)

There were some academic papers that stated that a regular structure would raise efficiency. Further, with a randomly textured structure, if something is changed and the results thereby change, it is difficult to understand the causal relationship whereas with a regular structure, it is easier to elucidate what led to the results when hole size or depth, for example, are changed. Accordingly, the researchers decided to look at regular structures in 2010.

“Awareness of cost is crucial in the R&D of solar cells. For this reason, we are constantly searching for methods that are not only neat ways of making solar cells, but also low-cost ways. Oxidizing an aluminum substrate in a chemical solution was the first method tried as a low-cost and neat means.” (Matsui)

This was similar to the method for anodizing aluminum; as long as the parameters fell into place, a neat periodic structure could be fabricated. Hole size in the textured surface could be varied by changing the voltage. Using this method to make uniform textured structures and measuring their performance showed that the amount of light absorption could be raised if the holes were made larger.

Sai and his team were convinced that this was the way; however, a problem emerged. Pursuing even greater absorption, they tried to open up holes with sizes of larger than 1 μm but found that it was not possible. This essentially meant that this method could only make holes up to a certain size.

“After wracking our brains, we decided to switch to the photolithography<sup>\*6</sup> method. We already knew that photolithography imparted a great degree of freedom in designing structures but it had not been considered an option due to cost issues. However, we decided to focus on flexibility rather than cost and hence made the switch to photolithography. If results were achieved then cost would be dealt with later. We thought that we should first focus our efforts on improving performance.” Sai’s decision became a major turning point.

<sup>\*5</sup> **Amorphous silicon solar cell:** Amorphous silicon is primarily comprised of silicon and hydrogen atoms. In contrast with crystalline silicon, the material does not possess a perfect orderly structure. It absorbs light over the violet to red visible spectrum. Performance degrades with prolonged exposure to light.

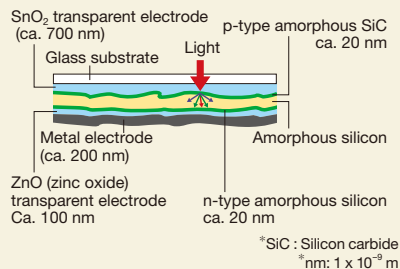
<sup>\*6</sup> **Photolithography:** Technology in which a substrate surface is coated with a photosensitive substance and patterns are then formed through partial exposure of the substance to light through a photomask. It is used as a fabrication process for printed circuit boards and semiconductors, etc.

## Terminology at a glance

### Thin film silicon solar cell

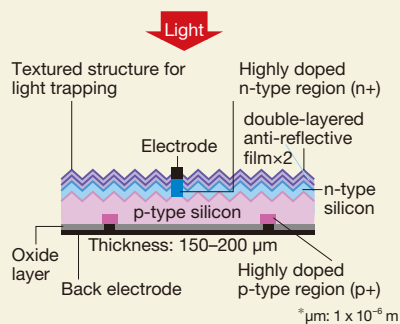
#### Structure of amorphous silicon solar cell

A structure comprising a stack of glass substrate, a transparent electrode, amorphous silicon (power generation layer), and a metal electrode. The thickness of the silicon layer is less than 1  $\mu\text{m}$ . This type is used in calculators.



#### Structure of crystalline silicon solar cell

A textured Si wafer is used as a substrate with metal electrodes on the top and the bottom. The thickness of the silicon substrate (power generation layer) is 150–200  $\mu\text{m}$ , which is thicker than the amorphous silicon type.



Source: Website of Research Center for Photovoltaic Technologies

#### Features of thin film silicon solar cell

Crystalline silicon	Thin film silicon
Thick (ca. 200 $\mu\text{m}$ )	Thin (0.3–3 $\mu\text{m}$ ) Consumption of raw material (high-purity Si) reduced to less than one hundredth
Silicon wafer (roughly half of module cost)	Deposited on low-cost substrates such as glass and plastic
Necessary to cut (generation of scrap)	No need for cutting Efficient utilization of raw material
Small area (ca. 20-cm square cells are connected together to make a module)	Larger surface area (film formation on substrate with several square meters in size)
Sensitive to high temperature (conversion efficiency drops with rising temperature)	Resistant to high temperatures Power generation in warm regions is high
High conversion efficiency	Low conversion efficiency

## One needs to look beyond just light to raise device performance

Luckily, AIST possessed shared nanoprocessing equipment and the technical staff also cooperated. Through opting for photolithography, Sai was relieved from the stress of not being able to make what he wanted and his motivation rose accordingly.

Day after day, uniform textured structures that looked like they would generate good numbers were fabricated and tested to see if they would perform as cells. Initially, however, when the researchers thought they had stumbled across a structure that would deliver, the results proved otherwise. Matsui talks here about his experiences in this respect:

“In the case of a thin film silicon solar cell, even if you have a substrate with good light trapping efficiency, that doesn’t mean the power conversion efficiency will increase once it’s part of a device. In actual fact it is very difficult to realize both good light absorption and good power generation.”

Wouldn’t a lot of power be generated if a lot of light were trapped? Sai answers this question:

“The form of the interface between the substrate and the silicon layer is important in terms of increasing light absorption and at the same time, it affects the quality of the silicon film that forms on it. Film quality can be adversely affected by the morphology of the interface and power generation efficiency ends up declining. In other words, even

if a suitable interface structure can absorb light well, this does not lead to performance as a cell.”

In order to develop a solar cell with better performance, one needs to take both light and the device into consideration, rather than just understanding light and fabricating the device. However, just as AIST has expertise regarding light absorption, it also possesses technologies for device fabrication. Expertise regarding the correlation between power generation efficiency and textured structure has also been accumulated. Moreover, Sai himself has experience with research into photonic crystals; he is also very knowledgeable about technologies for trapping light and controlling it. Combining these assets would surely lead to a breakthrough.

## Finally arriving at a hexagonal honeycomb structure

The point of using a textured structure for the substrate is so that it is effective no matter what direction sunlight is incident from. After simulating various shapes and forms, the conclusion was that a hexagonal arrangement raised efficiency by the greatest extent. So then, what was the best method to form a high quality silicon film on top of this? Sai and his team tested textures with various hole sizes, depths and shapes.

“The first structure that we investigated was V-shaped (an inverted pyramid structure). This structure is known to deliver the best performance for solar cells that employ silicon wafers.

## Development history

October  
2010

Photovoltaic Power Generation Technology Research Association (PVTEC) Consortium inaugurated under NEDO. AIST, together with PVTEC, Kaneka Corporation, Sharp Corporation, Panasonic Corporation, Mitsubishi Heavy Industries, Ltd., and others, carried out various R&D including the following: R&D of solar energy technologies; Photovoltaic Power Generation System - Development of Next-generation High-performance Technology for Photovoltaic Power Generation Systems; next-generation multijunction thin film silicon solar cell under a cooperative industry-academia-government structure.

March  
2011

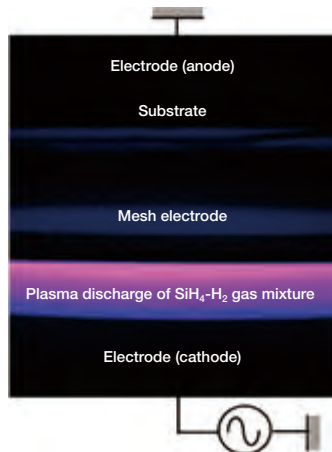
The method for fabricating a uniform textured structure is changed from anodic oxidation to the photolithography process.

March  
2013

A honeycomb textured structure is developed jointly with PVTEC. A thin film microcrystalline silicon solar cell using this achieved a power generation efficiency of 10.5%.

June  
2013

An amorphous silicon solar cell achieves an efficiency of 10.1% (tied world record) after stabilization of light-induced degradation.



▲ Triode-type plasma CVD used to form high efficiency amorphous silicon solar cell

Source: T. Matsui et al., Prog. Photovolt: Res. Appl. vol. 21, 1363 (2013).

Present-

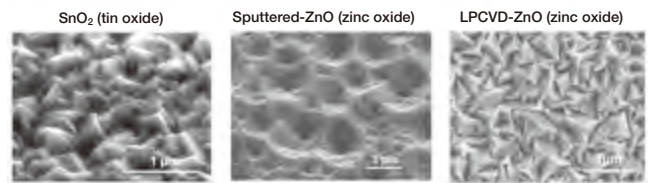
World's highest power generation efficiency for thin film microcrystalline silicon solar cell of 11% achieved. Targeting module conversion efficiency of more than 14% by 2015. Also pursuing faster film formation rate, larger substrate size, and multijunction structure with amorphous silicon solar cells.

However, when microcrystalline silicon films were formed on such V-shaped structure, cracks occurred in the films.” (Matsui)

Having said so, light is not reflected diffusely very well if the entire base of each hole is flat and therefore, the light absorption is adversely affected. With satisfactory results hard to come by, fine tuning of the parameters for fabricating the light trapping structure was doggedly carried out.

“During these efforts, a honeycomb structure just happened to eventuate in which part of the hole base was flat. Tests showed that there was no cracking, film quality improved, and good

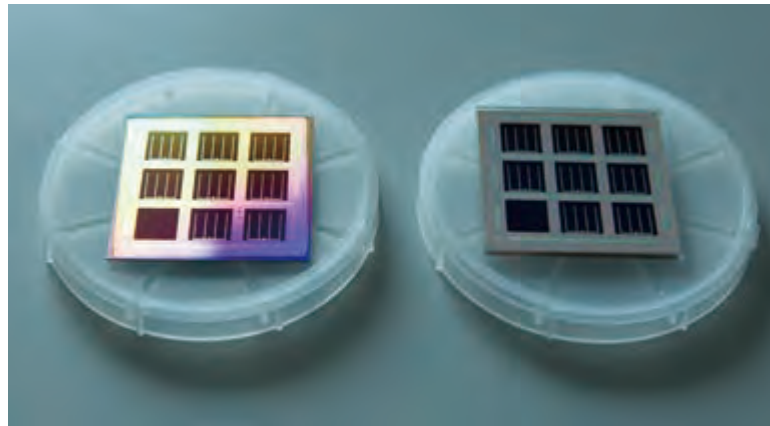
## Light trapping technologies utilized to date (randomly textured structure)



▲ Light trapping was insufficient with an irregular textured structure and power generation efficiency did not rise.

Source: Photovoltaic Cell Technology Handbook (Ohmsha, Ltd., in Japanese)

## Microcrystalline silicon solar cell



▲ The rainbow color shining in the left of this photograph was formed on a honeycomb textured structure. On the right is the conventional irregular structure.

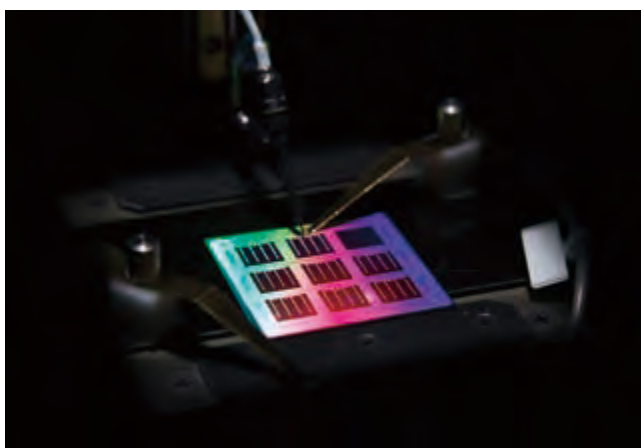
properties could be obtained. We grabbed this opportunity and subsequently were able to make great strides with our research.” (Sai)

Initially, a power generation efficiency of 9% was obtained and the team was certain that it could improve on this through further modifications. This was just the beginning.

“Until we got our first result, there was a period where I was uneasy regarding whether research was heading in the right direction or not. However, it was the only method available for accessing fields that couldn’t be developed with previous methods. Rather than having a strong conviction that this could be done, I was of the feeling that we’d probably be OK and we had no choice but to go ahead. We were convinced that the direction we took was correct once we had verified a power generation efficiency exceeding that of conventional structures.” (Sai)

## A combination of multiple solar cells improves power generation efficiency

Subsequently, unexpected issues emerged, such as the need to control the size of the textured structure in relation to the thickness of the silicon layer but after a series of improvements, the world-record power generation efficiency for a thin film microcrystalline silicon solar cell of 11% was achieved in February 2014. Efficiency is continuing to improve



▲ Measuring the performance of samples using the Solar Simulator, an apparatus that emits light simulating sunlight

and moving forward, the research team believes that it will achieve even better results.

“The sunlight wavelength range that a solar cell can absorb is dependent on its type; so, in order to achieve a broader absorption band, one generally opts for a thin film silicon solar cell with a multijunction structure.<sup>\*7</sup> In the future, we are aiming to improve the power generation efficiency further through combinations with the amorphous silicon solar cell that I developed.” (Matsui)

Green innovation that contributes to solving environmental issues is one of the pillars of AIST alongside Life Innovation. The Fukushima Renewable Energy Institute<sup>\*8</sup> was established in Koriyama, Fukushima Prefecture by AIST in April 2014 with the objective of realizing early large-scale deployment of renewable energy. Allying with this institute, R&D of even higher performance solar cells will be advanced moving forward, thereby contributing to solving energy-related issues.

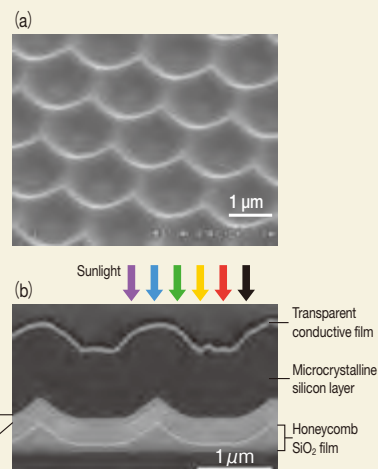
\*7 **Multijunction structure:** A solar cell structure that incorporates several types of solar cells in series absorbing different wavelengths of sunlight, thereby absorbing all wavelengths of sunlight and delivering a high conversion efficiency. The output voltage is the sum of the voltages of each cell.

\*8 **Fukushima Renewable Energy Institute:** A research base opened by AIST in April 2014 in Koriyama, Fukushima Prefecture, with the objective of developing and making available new technologies related to renewable energy. Its dual missions are “the promotion of R&D into renewable energy that is open to the world,” and “to make a contribution to industrial clusters and reconstruction.”

## Terminology at a glance

### Honeycomb structure texture

A honeycomb structure with orderly-arranged hexagons (a). Viewing its cross-section (b), one can see that parts of the hole bases are flat. When the diameter of an individual hole is roughly equal to the thickness of the microcrystalline silicon film, light absorption increases the most.



## A vision of the future

### The future of thin film silicon solar cells

It is common for thin film silicon solar cells to be multijunction types and for this reason, it is important not only to improve the light absorption of microcrystalline silicon, but also of the other solar cell types used in combination in order to raise the performance of the overall solar cell.

The power generation efficiency of AIST’s microcrystalline silicon solar cell, at 11%, is the world’s best. Further, AIST is also tied for the record for the highest power generation efficiency for an amorphous silicon solar cell at 10.1%. Moving forward, by combining these solar cells, new solar cells with even higher efficiency should be achievable. The current multijunction type world record is 13.4%. The initial target is to exceed this level.

Furthermore, our dream is that the fruits of this work will be returned to society so that everyone will be able to use them.



# Technology to decipher the glycan – “Face of a cell”

## A glycan biomarker enables convenient hepatitis testing and diagnosis

### Contributions anticipated in medicine and drug development

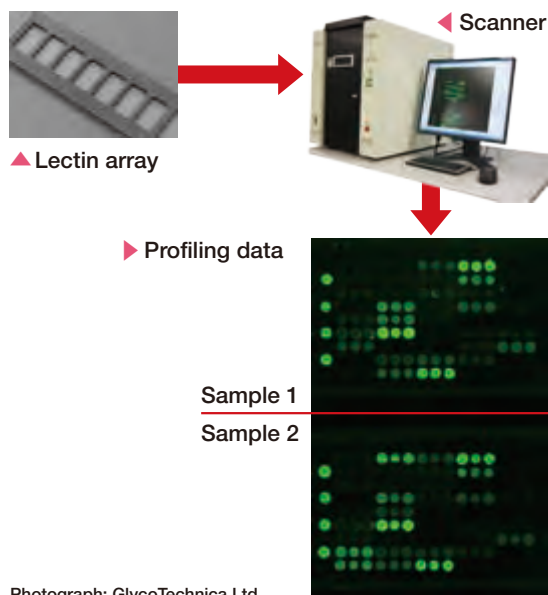
Glycodiagnosis & Drug Translation Research Party, Glycomedicine Technology Research Center

**Our life and society will change in this way!**



Glycans are complex in structure; little progress has been made in analysis to elucidate their roles and functions. AIST's lectin array, however, has facilitated structural analysis and led to development and commercialization of a diagnostic system consisted of a glycan biomarker for liver disease. This diagnostic system enabled patients to receive appropriate treatment and medication. Further development and practical application of new glycan biomarkers would contribute to efficient and effective treatment of more diseases.

#### Glycan profiling process



Photograph: GlycoTechnica Ltd.

#### Glycan: related to vital phenomena

Glycans are components attracting significant attention as the “third chain of life” in addition to DNA and proteins. Glycans consist of various sugar moieties linked together in a chain structure, and glycans bound to proteins and lipids are present on the surfaces of all cell types that constitute living organisms. The surface glycoproteins and glycolipids connected to other cells induce various mutual interactions. For example, if a particular glycan on the surface of a different species (foreign substance) such as a pathogen binds with an immune cell, the organism acquires immunity. Glycans control cell activity, such as recruitment of white blood cells at lesions where bleeding occurs. Glycans are also used for infection by viruses and pathogenic bacteria that enter the body.

“Glycans are involved with all sorts of vital phenomena. Therefore, if their roles and functions can be clarified, this will surely contribute greatly to medicine and drug discovery. However, glycan structures are far more complex compared to those of DNA or proteins; therefore, not much progress has been made in structural analysis of glycans.” says Atsushi Kuno, Chief Senior Researcher in the Glycomedicine Technology Research Center. Not only are glycan structures complex, but also very many types exist. Moreover, what makes it further complicated is that their forms change according to the changes of cell types and status.

#### Development of a glycan profiling system

In 2005, the situation was changed drastically by the establishment of a new system: the lectin array glycan profiling system (commercialized in 2006 by Moritex Corporation (currently GlycoTechnica Ltd.)), in which Kuno was deeply involved in the development.

“The lectin array is comprised of around 40 types of glycan-binding proteins called lectin immobilized in an array on a glass slide; each lectin recognizes and binds to specific structures of glycans. AIST has compiled a database of which lectins display high affinity to what types of glycan structures.





- Food
- Safety and security
- Healthcare, welfare, care giving



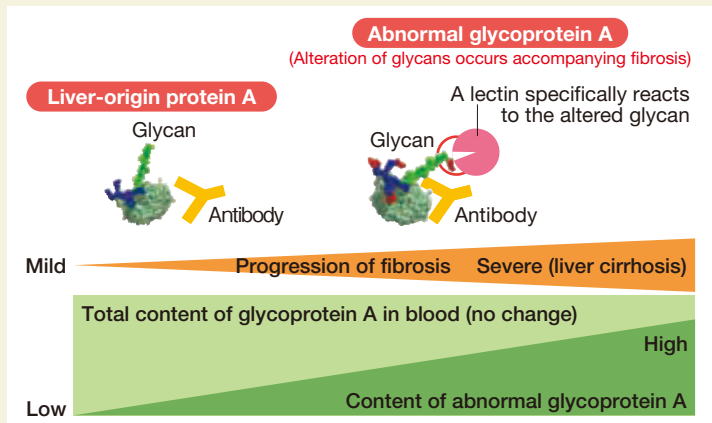
- Health care, welfare, care giving
- Chemistry, biotechnology
- Food

## Terminology at a glance

### Structural change in a glycan accompanying disease progression

This diagram illustrates the relationship between progression of fibrosis, which indicates the state of the liver, and the frequency of structural change occurring in a glycan incorporated into blood "Glycoprotein A" that is originally expressed in the liver. Because the core protein moiety does not undergo structural change, both Glycoprotein A expressed from a normal part of the liver and abnormal Glycoprotein A expressed from cells affected by fibrosis react with the antibody against the core protein.

If a lectin that reacts specifically with the glycan of the abnormal Glycoprotein A can be found, it will become possible to quantify the abnormal Glycoprotein A that reflects the progression of fibrosis.



Source: AIST TODAY Vol. 14, No. 6

The mechanism entails "reading" a glycan with a scanner and, with reference to the database, identifying (profiling) the characteristics of the glycan such as linkages and degrees of branching."

Liquid chromatography<sup>\*1</sup> and mass spectrometry<sup>\*2</sup> have been used as methods for glycan analysis, but their sensitivities and simplicities were not sufficient. In comparison, the lectin array employs a technique that can detect the weak interactions between glycans and lectins and has the world's highest sensitivity. It also features simple operation; a technical assistant can become capable of analysis after just one month of training.

### A diagnostic test that shows progression of symptoms in hepatitis in 17 minutes

A path to utilizing the functions of glycans was thereby created through this simple analytical method. NEDO and AIST kicked off the Medical Glycomics Project in 2006. Thereupon they made a breakthrough discovery. The glycans in a specific protein in the blood were found to change progressively with the progression of symptoms in viral hepatitis patients.

Viral hepatitis is a disease that, if it progresses, can lead to hepatocellular carcinoma. Until now, the detailed examination for investigating the state of the liver has been done by direct insertion of a needle to extract a tissue sample (needle biopsy) for judgment by a pathologist. The physical and financial burden on a patient using this method was substantial; the biopsy was risky as well.

"If a simple blood test can evaluate the progression of symptoms in hepatitis, the state of the disease –how better or worse the situation has become– can be examined at a certain interval from an earlier stage. In this way, optimum treatment can be commenced timely, and more effective administration of drugs will be possible."

AIST proceeded to work towards practical application of this technology for measuring the state of the liver by improving

the accuracy and accelerating the time required for diagnosis. In December 2013, the diagnostic agent was permitted as the world's first liver disease diagnostic system (liver fibrosis examination technology) on the basis of the concept of glycomarker<sup>\*3</sup> (commercialized by Sysmex Corporation). It only takes 17 minutes from setting the blood sample, and the patients can thereby be informed of the results on the same day they received the periodical examination.

While it is still in the clinical research phase, the diagnostic agent will eventually be covered by health insurance and be positioned as a low-cost diagnostic method. The technology was systematically developed in Japan, but it will likely be a savior not only for the 3 million viral hepatitis patients in Japan, but also for the world's 100 million-plus hepatitis patients.

"The development system that we have established is also applicable to develop other biomarkers<sup>\*4</sup> for examining various diseases. On this account, we expect that the system can be used to address many other medical needs. If a quantitative index for a disease can be established, it will be easier to investigate the efficacies of drugs. Consequently, it would contribute to accelerate the drug development that normally takes well over 10 years. We will continue with development of diagnostic reagents and therapeutic drugs based on the glycomarkers consistently toward their practical application through the industry-government-academia alliance."

\*1 **Liquid chromatography:** An analytical method in which a substance is injected into a stationary phase with specific properties and separated based on the differences in mobility of the various components to identify and quantify them. Specific components can also be purified using the process.

\*2 **Mass spectrometry:** An analytical method that identifies a substance and determines its structure at the atomic and molecular level based on the mass spectrum patterns of the substance.

\*3 **Glycomarker:** A biomarker based on the glycans as indices. In general, the indices are defined as the altered glycans or glycosylation change on a protein along with the progression of disease or a change related to biological event.

\*4 **Biomarker:** An indicator that expresses biological information in a numerical form in order to quantify a change in an organism. For example, levels of blood glucose and cholesterol are biomarkers indicating lifestyle diseases.

## The quantitative NMR method: Correctly measuring amounts of organic compounds

# An innovative measurement technology for rapidly and moreover accurately measuring the amount of substance (mole)

## Major contributions to the environmental, food and pharmaceutical fields

Chemical Measurement System Section/Metrological Information Section, Measurement Standards System Division, Metrology Institute of Japan

**Our life and society will change in this way!**



There are vast needs in industry and society for measuring amounts of organic compounds such as pesticide residues in foods and pharmaceutical ingredients but it is taking time and effort to create measurement standards to function as yardsticks for responding to such needs. The quantitative NMR method is capable of swiftly and moreover accurately measuring the amount of a substance (mole); development of measurement standards for pesticide residue testing, etc., is proceeding rapidly. In the future, one can anticipate deployment of this technology to result in a safe and secure environment throughout the world in fields such as environmental protection, foods and pharmaceuticals.

### Were there no measurement standards for chemical substances?

The mass media has in the past reported “residual pesticides exceeding standard values detected” while health screenings have also indicated “cholesterol levels higher than standard values.” Needless to say, we think that these substances are being measured accurately. However, it is extremely difficult to accurately measure chemical substances, in particular organic compounds. In actual fact, there are international measurement standards<sup>\*1</sup> for length and mass (weight) but when it comes to amounts of organic compounds, very few measurement standards exist. Measured values in health screenings are, therefore, “values thought to be roughly correct.” “Although a single metric suffices to measure length, organic compounds possess various molecular structures; therefore, in order to accurately know its quantity, a measurement standard of

the substance that was to be measured (a reference material<sup>\*2</sup>) was required. For example 10 types of reference materials were required in order to measure 10 types of agricultural chemicals; moreover, it took years to produce a reference material for one compound.”

Chemical Measurement System Section Chief Toshihide Ihara explains why this was the case.

Companies and organizations possessing analytical equipment can obtain correct results for their measured values through comparison with reference materials. Without reference materials, they have no way of knowing whether their measured values are higher or lower than the standard value. However, preparation of such materials has not kept up with demand. In recent years in particular, awareness of safety and security has risen and more regulatory measures are being introduced. For example, in 2006, the number of agricultural chemicals regulated by the Food Sanitation Act increased from approximately 250 to around 800. With this alone there was now a need for approximately 800 reference materials. Using a reference material reduces the quantity remaining; for this reason, companies copy the original reference material (national reference material<sup>\*3</sup>) and manufacture a working reference material in large quantities for use in actual tests. But in any case, there is the initial requirement for a national reference material as the original.

“At this time, Japan only possessed two types of national reference material for testing of pesticide residues in food. There were almost no standards to guarantee the reliability of measurement. Furthermore, with existing technology it would have taken several dozen years to supply all of the required reference material types.” (Ihara)

AIST was in a position to develop national reference materials in Japan; Ihara and his colleague Takeshi Saito, Chief of the Metrological Information Section, wanted to establish a means of supplying reference materials to society over a shorter time frame.

### A common standard realized for the first time

The two scientists came to focus on the nuclear magnetic resonance (NMR) method employed in the analysis of components of organic compounds. In this method, atomic nuclei contained in chemical substances resonate in a strong magnetic field; analysis of the resonance signals enables elucidation of the substance’s molecular



- Food
- Environment
- Safety and security
- Medical treatment, welfare, care giving



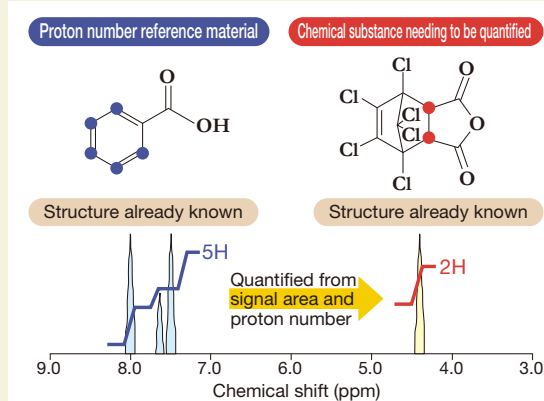
- Environment, resources, energy
- Medical treatment, welfare, care giving
- Chemistry, biotechnology
- Food
- Agriculture and fisheries

## Terminology at a glance

### Quantitative NMR method

When atomic nuclei that possess a nuclear magnetic moment are placed in a static magnetic field generated by a strong magnet, they adopt one of two spin states either aligned with or opposed to this magnetic field, and they precess like spinning tops. When a radio frequency is applied to these nuclei, they resonate at different frequencies depending on their moiety in the molecule. Their resonance signals can be expressed as a frequency spectrum (chemical shift).

The NMR signal area is independent of the substance's structure. It is actually proportional to the number of the resonated nuclei and the signal area in proton NMR can thus be used to compare numbers of protons. Based on this fact, using the signal area of a reference material whose proton number is known, as long as the structure of the other substance is known, the signal area and the number of protons contributing to this signal can be applied in calculating the quantity of this component.



structure. The signal area obtained from hydrogen nuclei (protons)<sup>\*4</sup> in particular is known to be proportional to the number of protons present. If this is the case, wouldn't it be possible to measure the amounts of various chemical substances by using a substance for which the number of protons is known as a basis for comparison with the number of protons of the target substance?

"Initially the measurement error was more than 10% and as such, this low level of accuracy meant the method could not be practically applied as a quantitative method for reference materials. However we decided to focus on the high versatility of the NMR method that could measure protons that are present in almost all organic molecules, raise its accuracy, and attempt to apply it practically as a quantitative method for reference materials." (Saito)

R&D started in 2006 and by 2008 they were able to deliver the accuracy demanded for quantitative analysis of reference materials. Through the birth of this quantitative NMR method, a single national reference material was all that was needed in order to be able to quantify various other chemical substances.

"By establishing a common standard of the proton, we were now able to swiftly and accurately measure the amounts of various organic compounds. Through this, it was no longer necessary to prepare a national reference material for each chemical substance type and practical reference materials could now be disseminated to a society that demanded them." (Ihara)

The quantitative NMR method was established at AIST. However, at this stage the vast majority of NMR instruments users were not focusing on this technology. This was because there were no how-to guides demonstrating appropriate implementation of this method; neither were commercial reference standards for the number of protons nor software for quantitative measurement available. One could say that the required infrastructure was not in place.

Thereupon, five organizations from the private and governmental sectors came together in 2008 to enable anybody to use quantitative NMR. They were AIST, the National Institute of Health Sciences (NIHS, under the Ministry of Health, Labour and Welfare), JEOL RESONANCE Inc./JEOL Ltd., Wako Pure Chemical Industries, Ltd., and Kao Corporation. They commenced joint research to

solve technical and legal issues, and to bring this technology to the stage of widespread adoption for the first time in the world.

The cooperation and efforts of these partners led to commercialization of software, reference standard for the number of protons, and other elements for the quantitative NMR method, which was adopted in the Food Sanitation Act (Japanese Standards of Food Additives) in 2011 and the Pharmaceutical Affairs Act (Pharmacopoeia of Japan) in 2014. In addition, close to 200 practical reference materials for pesticide residues in food testing were furnished in the short space of several years. The fruits of this joint research were remarkable, with researchers receiving numerous awards at academic meetings and being recognized both in Japan and abroad.

In 2014, the Bureau International des Poids et Mesures (the global headquarters of measurement standards)<sup>\*5</sup> started a five-year joint international research project with AIST. It won't be long until this innovative measurement technology developed in Japan will become a global standard. Today, objective debates on various chemical substances are starting to become possible using data based on the scientific basis obtained from the quantitative NMR method. Moving forward, we will more than likely see pursuit of safety and security at a very different level than see before throughout the world.

\*1 **Measurement standard:** The national standard for a unit that is employed as a "reference for measurement," such as length, mass, temperature, voltage.

\*2 **Reference material:** A homogenous and stable substance employed as a "standard" in calibration of analytical instruments and assessment of measurement methods. In the case of a chemical substance, one for which the concentration of a specific molecule is known.

\*3 **National reference material:** The original reference material conforming to a procedure prescribed by an international standard whose property value is expressed in SI units.

\*4 **Proton:** A sub-atomic particle that, together with electrons, forms atoms. Almost all atoms having both protons and neutrons present in their nuclei. Hydrogen atoms are the only type with nuclei not containing neutrons; their nuclei are comprised of single protons.

\*5 **Bureau International des Poids et Mesures:** The secretariat and research organization based on the outskirts of Paris, France whose roles are to ensure the equivalence of measurement throughout the world and traceability to the International System of Units (SI).

# Identifying risk prior to great earthquake/tsunami occurrence

## The 1100-year old Tohoku tsunami disaster recorded in coastal deposits

### Utilization to prepare for future earthquake/tsunami

Subduction Zone Paleearthquake Research Group, Institute of Earthquake and Volcano Geology

**Our life and society will change in this way!**



**The fact that research of tsunami deposits revealed the risk of the Great East Japan Earthquake and Tsunami occurring before it even happened has led to a growing emphasis on a geological approach to earthquake prediction. If geological surveys can reconstruct damage from earthquakes and tsunami over an extended time span, future earthquake risk can be concretely anticipated, and effective countermeasure can then be implemented.**

#### A major earthquake reported to be a one in a thousand years event

The giant tsunami that resulted from the March 2011 Great East Japan Earthquake inundated large areas of land centered on the Tohoku region and caused immense damage. AIST's Subduction Zone Paleearthquake Research Group<sup>\*1</sup> had in fact reported in the previous year the possibility of a great earthquake and accompanying tsunami occurring in the Tohoku region in the future based on observations that the region was affected by a tsunami every 450–800 years. Accordingly, the “once every 1000 years” giant earthquake was not necessarily beyond anticipation.

Yuki Sawai, Senior Researcher and group member who was engaged in the research explains.

“Reliable historical records and the findings of active fault surveys are used for long-term prediction of earthquakes but prior to the 2011 giant earthquake, little attention was paid to tsunami deposits. AIST is aiming to link observations of

groundwater level variations<sup>\*2</sup> and tectonic movements with predictions of the Nankai Trough megathrust earthquake.<sup>\*3</sup> In comparison to this, the geological approach was until now considered vague and little attention was paid to it.”

However, the importance of learning from the past was shown by the research of Sawai and his colleagues.

#### The past of several thousand years ago written in strata

Subduction zone earthquakes cause sea-floor displacement and such deformation makes tsunami that may subsequently inundate land areas. Research on tsunami is lively in Japan on account of the high frequency of earthquakes and the country being surrounded by the ocean on its four sides. However, documents of tsunami history are little the further one goes back in time. Instrumental observation records go back only around 100 years. Historical records extending back to a maximum of around 1400 years can also be used, but the only data available with high reliability is that from the Edo period (1603-1868) or later.

“Such data cannot capture earthquakes where the interval between reoccurrence is prolonged. However, a method that investigates past earthquakes and tsunami using geological records could potentially be applied over a time scale of several hundred to several thousand years.”

The Nihon Sandai Jitsuroku (sixth of the six classical Japanese history texts)<sup>\*4</sup> published in the Heian period records a great earthquake and tsunami occurring in the Tohoku region in the year 869 (known as the Jogan Earthquake and Tsunami). The occurrence of this earthquake had been known for a long time and in the 1990s, deposits from the Jogan Tsunami were discovered. However, these findings were omitted from the long-term forecast for subduction zone earthquakes of Japan's Headquarters for Earthquake Research Promotion because details of this earthquake was not clear.

Tsunami deposits are comprised primarily of ocean floor sand that is thrown up onto land due to a tsunami and are preserved as a sand layer. Sawai and his colleagues investigated such tsunami deposits in further detail and after taking into consideration the position of the coastline at the time, succeeded in producing an



- Residential
- Disaster prevention
- Safety and security
- Social infrastructure
- Transportation



- Environment, resources, energy
- Building and construction
- Agriculture and fisheries
- Geology

approximate inundation area for the Jogan Tsunami. Sawai's findings indicate that the inundation area of the Sendai Plain due to the Jogan tsunami was more extensive than that of any tsunami recorded before 2011. Furthermore, Sawai and his colleagues combined their findings with computer simulation and attained estimates of the origin of the Jogan Earthquake's tsunami and the earthquake's magnitude. Details of this earthquake were previously unclear on account of its occurrence so many years ago.

### Creating a framework for leveraging these research findings is important

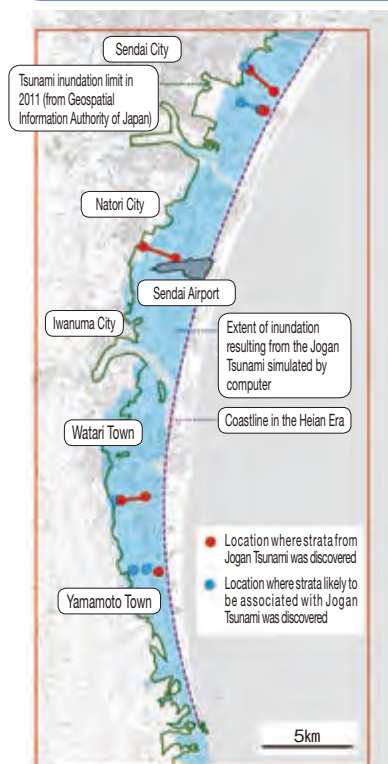
The research findings were reported to the Japanese Government in 2010. However, the long-feared great earthquake and tsunami occurred before the government could announce them as an official opinion.

"The scale of damage could be estimated from the magnitude. We were very grateful for the assistance from the local population for our survey. However, we were unable to think coolly about the implications if our research findings were correct."

After the disaster, the fact that these findings were disregarded even though they showed the risk of a great earthquake and tsunami based on geological study became the focus of much attention. Sawai himself says he regrets that his discovery was not widely recognized.

However, appreciation of the value of estimating tsunami damage changed significantly as a result of the disaster. Expectations for geological research were rapidly raised. Even

### Inundated areas in the vicinity of Sendai due to the Jogan Tsunami as inferred by AIST

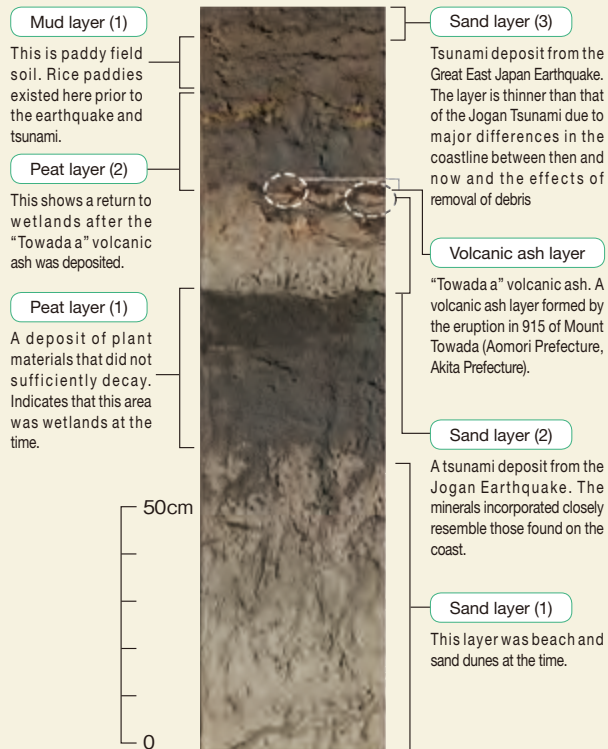


Source: Adapted from Geospatial Information Authority of Japan 1/25000 scale topographic maps: Shiogama; Sendai-Tohokubu; Sendai-Seihokubu; Sendai-Seinanbu; Sendai-Tonanbu; Iwanuma; Sendai Kuko; Watari; Kakuda; Marumori; Arahama; Yamashita; Shinchi.

## Terminology at a glance

### Tsunami deposit

A cross-section strata sample from the Sendai Plain. One can investigate the circumstances of this region over more than 1000 years from the ca. 120-cm thick deposits



Source: Amended from GSJ Geological News, Sawai (2014) (in Japanese)

Japan's Central Disaster Prevention Council revised its previous approach, identified earthquakes and tsunami presumed likely to occur based on analysis of historical documents, tsunami deposit surveys, coastline morphology, and other scientific knowledge, and signaled its intent to adopt a comprehensive approach that incorporated aspects including seismology, geology, archaeology, and history.

"Just how our findings are utilized is important. Moving forward, we will emphasize the importance of research into the past while at the same time, engage in education and outreach so that interest in geology is not lost."

\*1 **Subduction zone earthquake:** In a subduction zone, an oceanic tectonic plate and a continental tectonic plate converge through plate motion, resulting in the leading edge of former being drawn under the latter and into the mantle. An earthquake occurs once the strain that builds up through this overlapping motion reaches a limit, resulting in the continental plate springing up.

\*2 **Nankai Trough megathrust earthquake:** An earthquake of magnitude 8-9 feared to occur on the near future with a hypocentral region located at the Nankai Trough plate boundary.

\*3 **Groundwater level variations:** AIST is measuring water level variations in order to predict earthquakes by using the phenomenon whereby certain groundwaters (hot spring waters) react sensitively to swelling and compression of the ground.

\*4 **Nihon Sandai Jitsuroku (sixth of the six classical Japanese history texts):** A history book covering happenings in the period 858-887 compiled in the Heian period. Authors involve Tokihira Fujiwara and Michizane Sugawara.

# Research on risk management for radioactive substances in Fukushima

## Scientifically expressing decontamination effectiveness and costs, and radiation doses

### Data and assessment methods to help policy decision-making

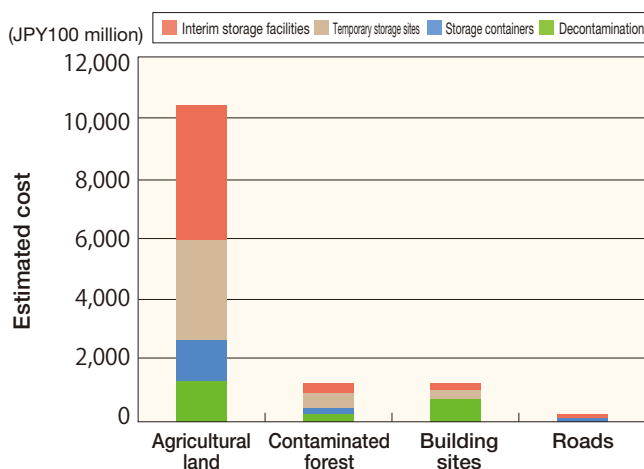
Geo-Environment-Risk Research Group, Institute for Geo-Resources and Environment  
 Risk Assessment Strategy Group, Research Institute of Science for Safety and Sustainability

**Our life and society will change in this way!**



The accident at the Fukushima Daiichi Nuclear Power Plant contaminated a wide area with radioactive substances. One year after the disaster, as of March 2012, the effectiveness of decontamination and its cost were still unclear, as were radiation doses to individuals during the course of their actual daily lives. However, if objective and quantitative assessment became possible, it would become easier to concretely debate these issues, and assistance would also be provided to local governments in the formation of future policies and establishing a framework in preparation for future risks.

Estimated decontamination cost using Basic Scenario<sup>4</sup>



▲ Decontamination costs for Special Decontamination Areas. Decontamination costs for agricultural land are estimated to account for ca. 80% of the total. Administrative costs, transportation costs and declines in productivity attributed to difficult-to-return zones are not taken into account. These effects are taken into account in the cost estimates presented in this article.

### No forecast without data

To what extent does the air radiation dose<sup>\*1</sup> in areas that have been contaminated by radioactive substances decline after decontamination? Will people evacuated from these areas ever be able to return to live there? What will be the overall cost of decontamination come to? A sizable population centered on Fukushima Prefecture is confronted with such issues with radioactive substances even today. Furthermore, even after decontamination work has been completed and it becomes possible for people to return home, these issues will affect the number of households that return, age composition, and how the post-return community will operate.

“Comprehensive and moreover long-term data regarding decontamination effectiveness and costs is required in order for local governments and citizens to manage these areas. However, as of March 2012 when this research commenced, such fundamental and comprehensive information did not exist.” While Tetsuo Yasutaka, Senior Researcher at the Institute for Geo-Resources and Environment, was visiting the region as part of a post-nuclear accident survey, he came to the conclusion that furnishing data that would form a basis for policy debate would be indispensable to appropriate risk management and countermeasures for radioactive substances. Subsequently, in April of 2012, cooperating with 13 other researchers from within and outside of AIST, Yasutaka started research focused on solving issues associated with the means for decontamination.

### How effective is decontamination?

The first task was to ascertain the effectiveness and calculate the cost of decontamination. The efficiency of decontamination depends on the method and the environment. In addition, contaminated soil and combustible materials that have been removed from the environment must be stored at temporary storage sites, the volume of combustible materials must be reduced through incineration, and the resulting waste then stored at interim storage facilities for around 30 years before final disposal. The massive cost associated with storage

## Impact in the following fields!

- Community life**
- Food
  - Residential
  - Disaster response
  - Safety and security
  - Medical treatment, welfare, care giving
  - Social infrastructure
  - Transportation



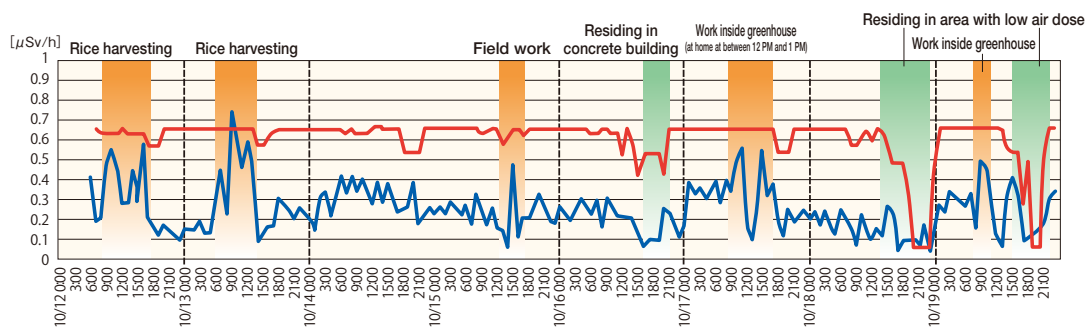
## Industry



- Environment, resources, energy
- Electronics
- Medical treatment, welfare, care giving
- Food, agriculture and fisheries

### Relationship between personal dose (blue line) and air dose (red line) (case study)

▶ The blue line shows D-Shuttle output (personal dose rate) and the red line shows airborne monitoring-based air dose rate determined by the GPS movement record. In general, personal dose is lower than air dose, while outdoor activity (rice harvesting and field work) results in higher personal doses.



was calculated as part of the overall decontamination cost.

“Data related to air dose rate, land usage, decontamination efficiency, etc., was systematically accumulated; a geographic information system (GIS)<sup>\*2</sup> was utilized to analyze decontamination effectiveness and costs. The findings indicated a cost estimate of approximately JPY1.2–2.0 trillion associated with Special Decontamination Areas<sup>\*3</sup> including storage of contaminated materials, and an overall cost for Fukushima Prefecture of JPY3–5 trillion including Intensive Contamination Survey Areas.”

In addition, the findings showed both quantitatively and geographically that in the short term, there are areas that do not meet the government’s target value for air dose rate even if decontamination is carried out. However, it is important to know the truth in order to move forward. Revealing such data for the first time allows us to stand on the starting line to concretely consider “optimum solutions” for decontamination effectiveness and cost.

### Assisting in proper understanding of personal exposure and eliminating anxiety

AIST is engaged in research to assess personal doses. Air dose is not actually equal to personal dose: it varies depending on the movement pattern of the individual. For example, someone who is indoors for long periods such as an office worker will be exposed to a lower dose of radiation than someone who works outdoors. Understanding the actual radiation doses of individuals will lead to elimination of anxiety and understanding of policies.

The D-Shuttle personal portable dosimeter was useful for measuring personal doses. Regarding this usage, Wataru Naito, Senior Researcher at the Research Institute of Science for Safety and Sustainability, said: “By combining the measurements from D-Shuttle, GPS data, and individual activity records, we can elucidate which activities lead to high radiation doses. The relationships among activity, location and radiation dose become clear, and investigation of effective measures to reduce exposure becomes possible.”

Currently, AIST is collecting data from D-Shuttle dosimeters, GPS, and individual movement records with the cooperation of citizens of Fukushima Prefecture. Based on this data, AIST will then engage in development of methodologies and

### D-Shuttle portable dosimeter

▶ The D-Shuttle portable dosimeter used in the survey of personal doses (middle; developed by AIST and commercialized by Chiyoda Technol Corporation) and the GPS logger (left). The D-Shuttle is very compact and consumes little power. Its batteries last for approximately one year.



evaluation systems for estimating radiation dose that are in line with actual conditions on the ground.

“Based on this data, we can provisionally estimate the recommended air radiation dose in living environments in order to attain target radiation doses taking into consideration individual activity patterns. We believe that we can provide valuable data based on actual measurements for considering effective measures to reduce exposure.” (Naito)

“Moving forward, we want to furnish local governments with data for problem solving and see them apply it to the decision-making process. In addition, we hope that this data can be of use in deciding on a framework that prepares for whatever critical state might occur in the future.” (Yasutaka)

While conclusions are not easy to draw, AIST’s provision of objective assessment data has enabled the start of concrete discussions. The significance of this is considerable.

\*1 **Air radiation dose:** The amount of radiation (gamma radiation) existing in the air each hour. Unit is  $\mu\text{Sv}$  (microsievert)/h.

\*2 **Geographic information system (GIS):** A computer system that captures, stores, manipulates, analyzes, manages, and presents various types of spatial or geographical data.

\*3 **Special Decontamination Area:** Areas where decontamination work is proceeding as part of the decontamination plan drawn up by the national government. Indicates Planned Evacuation Areas where there is danger of an annual cumulative dose after the accident of 20 mSv and the Restricted Area lying within a 20-km radius of the Fukushima Daiichi Nuclear Power Plant.

\*4 **Basic scenario:** This scenario assumes removal of 5 cm of topsoil from agricultural land, removal of fallen leaves and humus from forests located within 20 m of areas of habitation, cleaning of roofs and walls of buildings, pruning of garden trees, removal of top soil (2–3 cm), and shot blasting of roads. Interim storage facilities are assumed to reduce the volume through incineration of combustible materials; to store the resulting ash in landfills designed for high concentration, leachable materials (strictly-controlled landfill sites); and to store soil (incombustible) in landfills for low concentration, low leachability materials (controlled landfill sites).

# Energy-efficient pressurized fluidized bed sewerage sludge incinerator combined with turbocharger

## Next-generation incineration system slashing electricity consumption by 40%

### Suppressing greenhouse gas emissions and contributing to preservation of the environment

Clean Gas Group, Energy Technology Research Institute

**Our life and society will change in this way!**



The sludge that remains after the treatment process for sewerage discharged through our day-to-day life is incinerated. This step consumes a vast quantity of energy and in doing so large volumes of greenhouse gases are discharged. The pressurized incinerator developed by AIST uses 40% less energy compared to conventional incinerators, while greenhouse gas emissions have been slashed by 50%. The burden on the environment can be significantly reduced if this new type of incinerator can replace incinerators currently in operation when they reach the end of their service lives.

Pressurized fluidized bed sludge incinerator combined with turbocharger currently operating



▲ Turbocharger

◀ Overall view

Photograph: Asakawa Water Reclamation Center, Bureau of Sewerage, Tokyo Metropolitan Government

### Achieving both energy conservation and environmental protection

The quantity of sewerage sludge<sup>\*1</sup> discharged in Japan has been increasing year-by-year in parallel with increasing adoption of sewerage treatment systems. While the majority of sewerage sludge is incinerated, it still contains approximately 80% water content even after dewatering and it is difficult to incinerate in this state. For this reason, large quantities of auxiliary fuels such as town gas and heavy oil are co-fired for incineration.

Furthermore, a fan is also required to supply air for sludge combustion, as is an induced fan for flue gas discharge after combustion, in order to operate the sewerage sludge incineration system. The issue here is that the energy consumed in driving these fans accounts for approximately 40% of overall consumption. In essence, these two fans are a major emission source of carbon dioxide (CO<sub>2</sub>) derived from electrical power. What is more, the nitrogen content of sewerage sludge is high; consequently, combustion results in large emissions of nitrogen oxides (NO<sub>x</sub>) and greenhouse gas nitrous oxide (N<sub>2</sub>O). In other words, major issues are associated with the conventional sewerage sludge incinerator in terms of energy consumption and environmental protection; thus, there are strong market needs for a new incineration system that takes the environment into account.

### Applying coal combustion technology to sludge treatment

Let's take a little look back in time to the 1990s. Group Leader Yoshizo Suzuki of Clean Gas Group at the Energy Technology Research Institute was at the time engaged in development of a fluidized bed combustor for burning coal under pressurized conditions. Pressurization enabled combined cycle power generation (through a gas turbine and a steam turbine); furthermore, the combustor could be downsized and NO<sub>x</sub> emissions reduced by accelerating the coal combustion rate. Consequently, hopes were high for the technology as a means of high efficiency power generation at thermal power stations. However, issues with economic viability and operational reliability saw the technology fade from the scene around 2000. At that time, Suzuki was participating in governmental





- Safety and security
- Eco products
- Social infrastructure



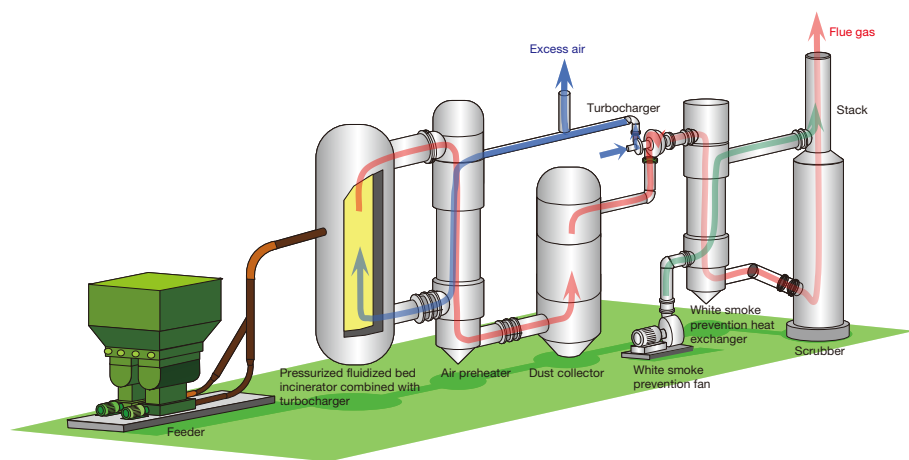
- Environment, resources, energy
- Machinery
- Food
- Agriculture and fisheries

## Terminology at a glance

### Turbocharged fluidized bed incinerator

The pressurized fluidized bed incinerator combined with turbocharger operates under pressure, with the turbocharger being driven by the high temperature, high-pressure waste gas from the incinerator. The turbocharger in turn pressurizes the air for combustion. The waste gas is discharged to the atmosphere by residual pressure and therefore, an induced fan is not required.

Source: Brochure of Tsukishima Kikai Co., Ltd.



multidisciplinary research and had the opportunity to speak with a researcher from the Public Works Research Institute under the Ministry of Land, Infrastructure, Transport and Tourism.

“When I was asked whether this system could incinerate sewerage sludge I answered in the affirmative. It turned out that the sector wanted to switch to a sewerage sludge incinerator type that saved energy. This chance encounter led to joint development of a new sewerage sludge incinerator.”

In this world you never know what may prove to be helpful. From this chance meeting, the Public Works Research Institute, AIST and private sector companies commenced joint development. Initially, they looked at recovering energy from the flue gas using a gas turbine in order to obviate the need for a fan but this turned out to be economically unviable at the scale of a sludge incinerator. The turbine option proved to be too expensive.

“So, could we instead use a low-cost turbocharger<sup>\*2</sup> to achieve the same functionality? This idea led to a breakthrough.”

Suzuki and his coworkers operated the incinerator under pressure and used the high temperature, high-pressure waste gas thereby generated to drive the turbocharger that in turn supplied compressed air for combustion. This setup evolved into the turbocharged fluidized bed combustion system.

### 10 years after research kicked off A next-generation standard is born

Suzuki employed a research apparatus built with coal in mind to elucidate the combustion characteristics of sewerage sludge under pressurized conditions. At the time, no such data existed. This effort took time, and basic research eventually gave way to R&D directed at commercialization. It was only in 2010 that the long-term continuous operation performance of the demonstration plant could be verified. It was thus 10 years from when R&D commenced until the technology was firmly established.

This next-generation sewerage sludge incineration system can be compact because combustion rate is accelerated by pressurization. Further, this leads a reduction of the quantity of auxiliary fuel required because of less heat loss. The two fans are also no longer

required and overall energy conservation in terms of electric power and other requirements of more than 60% is achieved.

“However, no matter how superior the system is, it had no track record whatsoever. The path to adoption was by no means smooth.”

Thereupon, the developers decided to target the Tokyo Metropolitan Government, which at the time had drawn up its Earth Plan (greenhouse gas reduction plan)<sup>\*3</sup> in the sewerage treatment field. Suzuki and his team promoted the energy conservation capabilities and low N<sub>2</sub>O emissions of the system and were successful in gaining the understanding of those in charge at the municipal government. Then, after conducting durability and operational tests jointly with the metropolitan government, the first system was delivered to Tokyo in March 2011. This resulted in an immediate boost to visibility of the technology in the sector. Moving forward, more than 200 incinerators are reaching the end of their operational lives throughout Japan and their replacement with new equipment is expected. The new system should be a leading candidate when the time to replace these incinerators arrives. In overseas markets, incineration is starting to become the mainstream method for sewerage sludge treatment and deployment of the technology overseas can also be anticipated.

“Through development of this technology, I learnt to not be narrow-minded and rather take hints from others in terms of where it can be applied, to disseminate information at academic meetings and through research papers, and to make the most of interactions with other fields. In the future, I plan to apply this technology for treatment of sludge generated from food production and livestock.”

\*1 **Sewerage sludge:** A muddy substance discharged as a result of wastewater and sewerage treatment.

\*2 **Turbocharger:** An apparatus that improves the thermal efficiency of internal combustion engines by raising the pressure of intake air to higher than atmospheric pressure.

\*3 **Earth Plan (greenhouse gas reduction plan):** A climate change prevention plan formulated in 2010 by the Bureau of Sewerage, Tokyo Metropolitan Government targeting 25% reduction in greenhouse gas emissions by fiscal 2020 (compared with fiscal 2000).

## Design technology based on sensory characteristics of older persons and persons with disabilities

# Targeting easy-to-read, easy-to-understand visual information for everyone

Summarized in JIS and ISO standards and published

Accessible Design Research Group, Human Technology Research Institute

**Our life and society will change in this way!**



**Accessible design enhances visibility and understanding for older persons and persons with disabilities. While broader application for accessible design is sought, to date no data for accessible design exists as an indicator. By standardizing the data and publishing it in the form of an interactive database, AIST believes that great strides will be made in adoption of accessible design. Moving forward, designs for better visibility and usability will surely increase.**

### Designs for young persons are hard to understand for older persons

The products, services and environments that surround us have to this day generally been designed and developed with young, healthy people in mind. However, such designs are not necessarily easy to see and easy to use for everyone. This issue came to the fore during the Great East Japan Earthquake and Tsunami of 2011. For example, power-saving measures introduced meant that some light sources such as fluorescent lighting in stations and in roadside vending machines were turned off, meaning there were no longer clues for direction and location. For some people, venturing outside alone thus became a challenge. Through this, it became apparent that while brightness may have been sufficient for sighted people to see, it was difficult for visually impaired persons such as those with low vision. In addition, important information was often distributed at evacuation centers on paper using standard font sizes and because no reading aloud services were available, for some

people it took time until such information was passed down.

Japan's senior population has been growing rapidly in recent years while recognition of the needs of persons with disabilities is also on the rise. On these accounts, wider application of accessible design that is easy to use for everyone including these two groups of people has come to be called for.

Barrier-free design and universal design are other terms based on a similar philosophy. The former involves removing barriers (obstacles) from products while the latter implies a design that is easy to use for all. The emphasis on "all" for the latter is strict and currently, this concept is not used to any great extent. Compared to these, accessible design is considered a more practical approach with a clear scope.

"Today, the industrial sector is enthusiastically engaged in accessible design. However, the sensory characteristics of individuals vary widely and furthermore, the types of low vision among visually impaired people vary significantly. For this reason, basic data that could function as guidelines for actual design did not exist."

So says Nana Itoh, Senior Researcher at the Human Technology Research Institute.

### Standardization of the sensory characteristics of the visually impaired from the data of 3000 persons

Data from several dozen to several hundred individuals is required in order to comprehend sensory characteristics by attribute and this is not easy to measure in terms of cost and effort. However, AIST has over the last fifteen-plus years measured various sensory characteristics such as vision, hearing, and sense of touch of more than 3000 older persons and persons with disabilities. Using this data, one should be able to generate basic data such as the characteristics of color perception by older people; which color combinations are easy to understand for visually impaired people; and the distribution of their visual performance levels.

In addition to this data set, Itoh and her colleagues

**Impact in the following fields!**

- Residential
  - Household goods
  - Safety and security
  - Medical treatment, welfare, care giving
  - Social infrastructure
  - Transportation
- Community life**
- Environment, resources and energy
  - Medical treatment, welfare, care giving
  - Design
  - Services
- Industry**

**From database of sensory characteristics of older persons and persons with disabilities**



▲ Legible font size based on age and other factors can be automatically estimated  
 URL: <http://scdb.db.aist.go.jp/?lng=en>



▲ The signage at Gunma Hospital. The hospital room door (left) employs color, pattern and font, with the room number being displayed in a low position. (Photograph: Kajima Corporation). The toilet door (right) employs easily distinguishable font size and contrast.

measured the sensory characteristics of persons in their 20's for comparison purposes; in 2009, they drafted a technical report (TR<sup>\*1</sup>) entitled "Data on span of similar colors of low vision". After having been reviewed by the Japanese Industrial Standards Committee's expert committee on elderly people/disabled people support working under the Standards Board, this TR was officially published by Japan's Minister of Economy, Trade and Industry in 2010 as TR S 0005: Data on span of similar colors of low vision. This is not a standard for product specifications; rather, it describes the data itself and standards for its use.

"This TR can be used to easily understand easy-to-see color combinations as well as combinations that are easily confused. Until now, the design of color schemes for signage, posters, assistive devices and the like that were easy to see by people with low vision was considered difficult but from now on, such efforts are likely to advance by leaps and bounds."

Some of the findings have been published as ISO standards<sup>\*2</sup> and can be utilized internationally. AIST was the first in the world to highlight this issue and unveil the methodology for dealing with it.

**Airports and hospitals adopt one after the other**

Based on data collected to date, an interactive and easy-to-use database of sensory characteristics of older persons and persons with disabilities was compiled in 2013. Users are able to freely select the category they want to use from a

database comprised of 17 categories classified under individual senses.

For example, let us try selecting legible font size. Inputting parameters such as the age of the person in question, the visual distance and the font type results in the "minimum legible font size," "good legibility font size" and "very good legibility font size" being displayed in the screen in actual size and numerically.

Further, by sliding the tool bars, one can intuitively understand how legible font size change with age and luminance.

"Previously, standards were released as publications so it took some time to understand their content and detailed calculations were required, among other issues. This database, however, can be readily utilized without any requirements for specialist knowledge and calculations."

This data is already being used in the design on signage at airports and hospitals and it has been rated highly. Data is starting to come together for senses other than vision, such as hearing and touch; this means it is now possible to comprehensively consider older persons and persons with disabilities. Moving forward, AIST will continue to measure and collect data on sensory characteristics and develop standards that enable more accessible design.

\*1 TR: Standards report presenting information on standard types that differ from Japanese Industrial Standards (JISS).  
 \*2 ISO standard: International standard prescribed by the International Organization for Standardization (ISO).

# AIST's challenge

## —National Institute for Advanced Interdisciplinary Research—

### World leading research organization and its accomplishments



Another success at AIST! Chapter in previous issues has introduced products and technologies created by the national laboratories (the predecessors of AIST) that contributed greatly to society. In this issue, rather than focusing on products and technologies, the spotlight is on an organization that existed in the past: the National Institute for Advanced Interdisciplinary Research (NAIR). We will look back at NAIR, an organization that was established with the objective of delivering findings that were global in significance, and consider the management for an organization that generates excellent results.

Photograph Source: NAIR brochure

#### A legendary organization melding multiple fields in an interdisciplinary manner

The National Institute for Advanced Interdisciplinary Research (NAIR) was established in January 1993 by the Agency of Industrial Science and Technology (the government agency that presided over Japan's technology research institutes prior to their unification under AIST). Its object was to achieve research findings that would be recognized globally. A revolutionary system was adopted in order to realize an organization capable of this; consequently, numerous world-leading results were produced in fields including strongly correlated electronic materials, colossal magneto-resistive material, biomaterials, nanoclusters, atomic and molecular level observation and manipulation, and computational science. Along the way, extremely capable talent also emerged. Later, Japan's national research institutes were reorganized and AIST was established in 2001. To date, AIST has achieved numerous findings but no matter how high an organization advocates its ideals, sustaining the freshness and tension of a new organization is difficult. So what is required in order that AIST may continue to be an organization that creates high level results? A reassessment of the legendary organization NAIR may provide hints as to what is required for such an organization.

The objective of NAIR was to pursue interdisciplinary research themes in advanced fundamental research fields based on international cooperation with the coming together of industry, academia and government from Japan and overseas. To achieve this aim, NAIR was inaugurated as an experimental research institute where several research fields were blended together to develop new research fields.

Further, an open, highly fluid, and highly international research framework was put in place, with implementing a fair evaluation system, to achieve concrete progress. Establishing these frameworks can be said to be the soul of NAIR. Before

looking closely at the organization and research framework of NAIR, let us first look at the context in which such a research institute was established.

#### Accusations of free riding on basic research; the shift to basic research

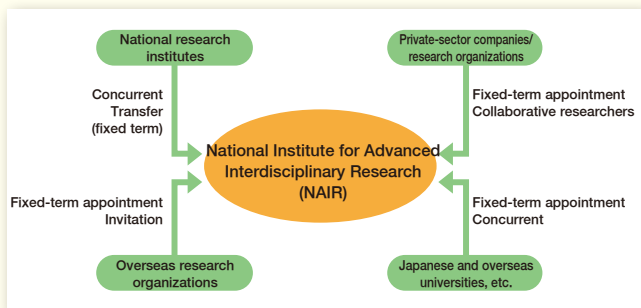
The 1980s was an era when Japan's economy was extremely buoyant, despite the fact that it was in essence a bubble economy that was to subsequently burst. Around this time, the Japanese government and private sector companies came together to implement applied research projects. Opposing this trend, criticism was mounting overseas, in particular in the US, regarding what was seen as free riding on basic research that was conducted outside of Japan; consequently, calls mounted for Japan to contribute internationally in a manner befitting its status as a leading global economic power.

Responding to these calls, the industrial sector started to pursue development of creative fundamental technologies through massive investment in basic research and hiring research staff and in the 1990s, the former Ministry of International Trade and Industry proposed a basic strategy of a shift to fundamentals and started to look at restructuring research institutes to keep them abreast of the times. One of the answers was the foundation of NAIR.

At the beginning of the 1990s, nanotechnology was already starting to be recognized as a common base technology for multiple industrial fields, such as new materials, electronics and biotechnology. Bringing diverse fields together was thus seen as indispensable for the further advancement of nanotechnology. In such an era, NAIR was born as a research institute to expeditiously promote projects with fixed deadlines. The first director at the time of NAIR's inauguration was Takanori Okoshi (former director of the Research Center for Advanced Science and Technology at the University of Tokyo).



### System for employing researchers



Source: Compiled based on NAIR pamphlet

The three research themes adopted when NAIR was established were ones viewed as difficult to advance as individual fields: Atom Technology, Cluster Science and Bionic Design. When considering that the US national project for nanotechnology was only announced in 2000, one can say that the former Ministry of International Trade and Industry was far-sighted in having initiated the projects seven years earlier.

Each project's duration was limited to five or ten years. Results were demanded within this time frame and budgets were on the whole guaranteed for the duration; thereby, a framework was established for research to proceed under long-term plans.

### Two revolutionary schemes for merging human resources from industry, academia and government

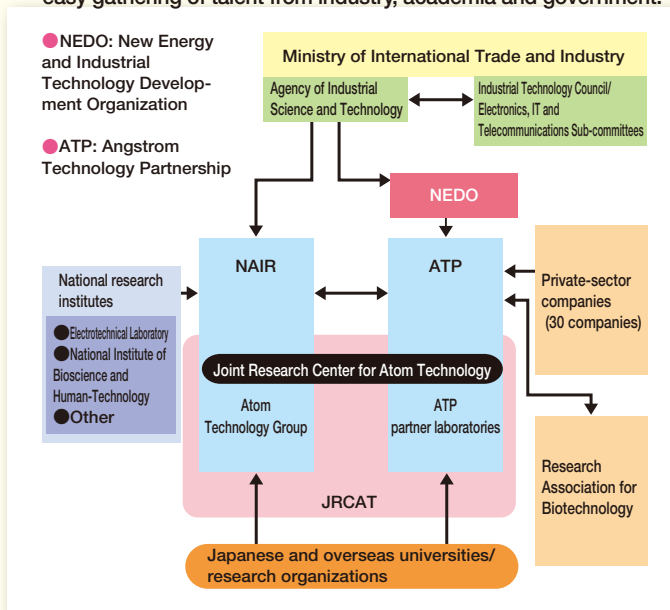
As previously mentioned, the number one objective of NAIR was to pursue progress in advanced research themes in fundamental and interdisciplinary ways. This endeavor was to involve industry, academia and the government and moreover involve international cooperation. An interdisciplinary approach was called for in terms of academic disciplines, industrial sectors, and human resources.

In order to realize this objective, a framework was with four distinctive characteristics: a research framework rich in openness, a research framework rich in fluidity, a research framework rich in internationality, and a research framework with objective assessments. Many researchers were hired for fixed terms in order to ensure openness and fluidity. A flexible management system was introduced to make researchers from academia, private sector companies and overseas organizations take part easily in the activities in the national research institutes. This was crucially important because the basic research can be conducted effectively through collaboration among various types of experience and expertise.

In addition, NAIR had a full-time research coordination and planning official with intimate knowledge of these frameworks (Takashi Gotoh a technical officer from MITI, at the time of

### Structure for mustering human resources for Atom Technology Project

Joint Research Center for Atom Technology (JRCAT) formed by NAIR and the Angstrom Technology Partnership (ATP). This enabled easy gathering of talent from industry, academia and government.



Source: Based on The Forefront of Nanotechnology: The Challenge of Atom Technology 1 (published in Japanese by Nikkei BP). Kazunobu Tanaka (Editorial Supervisor)/Masakazu Ichikawa (Editor)

establishment of the institute). This official would respond using the logic of NAIR to any issues that might emerge; thus, the ability to execute within national frameworks was maximized. NAIR had richer budgets for travelling overseas and inviting foreign researchers than other research institutes. Foreign researchers were staying constantly at NAIR; seminars were frequently held in English. Some foreign researchers even visited Japan to attend these seminars. The Atom Technology Project in particular made extreme efforts to gather talent. In addition to NAIR, a technology research association called the Angstrom Technology Partnership (ATP) was established; these two entities formed the Joint Research Center for Atom Technology (JRCAT). Private sector participants were seconded to ATP, while participants from universities either took up concurrent positions at NAIR or participated in ATP; all of these parties carried out research under the common umbrella of JRCAT. NAIR and ATP concluded a joint research agreement in order to preserve an equal partnership among researchers; thus, a fully committed industry-academia-government intensive collaborative research framework was realized. A major advantage was the impressive talent that was employed without hindrance by institutional barriers.

### The Atom Technology Project that influenced USA

Atom Technology had the largest scale of NAIR's three

## The leaders that carried the Atom Technology Project



▲ Kazunobu Tanaka,  
JRCAT Sub-leader (at the time)



▲ Kiyoyuki Terakura,  
JRCAT Sub-leader (at the time)

◀ Eiichi Maruyama, JRCAT Project Leader (at the time)

research themes. The planning of the project started three years prior to NAIR's establishment. It was proposed to NEDO as a candidate for a large-scale national R&D project promoting basic research through an industry-academia-government alliance by the electronic equipment section of the Machinery and Information Industries Bureau of MITI and duly selected. Here, the challenge was taken up to develop the ultimate technology for mankind that would create materials with new functionality through manipulation of atoms and molecules.

Ten research groups were engaged in projects, covering areas such as measurement and control technologies for atomic and molecular level structures, biomolecular measurement technologies, and first principles computational simulation technologies for large-scale analysis of semiconductor sub-nano structures. At its peak 107 researchers were involved. Normally, it was common for researchers to take tasks back to their organizations and work on them independently but with these projects, all of the researchers congregated at NAIR and focused on research under the auspices of JRCAT.

Further, the official languages were Japanese and English (important meetings were held in English). ATP stationed several dozen planning and support staff at NAIR to assist researchers in their efforts. Through this, the researchers were able to concentrate on research. Such a management system at the time was the first attempt without a precedent.

Tetsuo Shimizu was attempting to combine a scanning tunneling microscope with a mass spectrometer at the time (currently Chief Senior Researcher, Nano Optoelectronics Research Group, Nanosystem Research Institute); he recalls that "Walls between individual groups were low." By bringing together researchers from adjacent fields into a single location, discussions between these researchers would occur naturally.

Takao Ishida (currently Group Leader, Nanostructured Active Device Group, Nanosystem Research Institute) was involved with molecular electronics research utilizing organic self-assembled films; he said: "We brought in talented researchers from universities and private sector companies to form a dynamic and flexible organization that could collaborate

towards common goals."

The Atom Technology Project was driven by a troika comprised of a project leader and two sub-leaders. Further, these three were actual representatives of industry, academia and the government. For the first six years of the project, JRCAT Project Leader Eiichi Maruyama (currently an Emeritus Researcher at RIKEN) represented industry, Sub-leader Kazunobu Tanaka (currently an AIST Emeritus Researcher) government, and Sub-leader Kiyoyuki Terakura (currently an AIST Emeritus Researcher and a Professor Emeritus of the University of Tokyo) academia. In the latter four years of the project, Kazunobu Tanaka served as JRCAT Project Leader, while Tetsu Takeyama was sub-leader representing industry. These leaders were given a large amount of discretionary power in terms of human resources and budget. According to multiple researchers, one of the reasons why NAIR was so successful was the presence of talented leadership but this was surely related to this discretionary approach as evidenced by other comments: "Our bosses possessed strong resolve" and "Leaders that took the big-picture into account to provide positive leadership."

Over a ten-year period, the Atom Technology Project delivered groundbreaking results that contributed to current research of nanotechnology at AIST by creating the spintronics and strong-correlation electronic materials. In particular, the group headed by Yoshinori Tokura (currently a Director, RIKEN Center for Emergent Matter Science and a Professor of the University of Tokyo) published a total of 18 papers in prestigious journals such as Nature and Science, among numerous other publications. The Group also applied for 110 Japanese patents and 38 international patents. The Group's achievements shocked a US delegation that visited Japan in 1997 and the visit was reported to have affected the US National Nanotechnology Initiative.

### A culture that accepted failures and severe assessments that developed talents

The second theme of Cluster Science was related to Atom

## Cluster Science Project



▲ A technique combining resonance-enhanced multi-photon ionization time-of-flight mass spectrometry and infrared spectroscopy was developed to investigate structures.

◀ Group Leader Harutoshi Takeo (at that time)

Technology in that it handled atoms and molecules but its objective was to investigate from a chemical perspective whether aggregates of atoms and molecules possessed new properties and why.

Akihiro Wakisaka (currently Group Leader, Environmental Molecular Science Group, Research Institute for Environmental Management Technology) asserts: “NAIR was an excellent place to train researchers.” New challenges could be taken up and there was an abundant budget to support this. There was scope to accept failure and research seeds could be planted carefully and these led to well-founded research.

Wakisaka also mentioned the severity of the assessment committee that incorporated foreign experts in addition to external experts from within Japan. However, assessments were severe in order to generate improvements. In this way, researchers were forged and polished. Findings of the Cluster Science Project are being applied to current research at AIST into nanoparticle manufacture and a reaction field designed with electrospray in the liquid state.

## A valuable forum that could take on new challenges

The objective of the third theme, Bionic Design, was to establish design and manufacturing principles for organized structures and motion mechanisms that would mimic organisms. These were likened to multifunctional molecular machine systems. More than 50 researchers were engaged in cell and tissue engineering research and molecular machine research. The research scope encompassed development of bio-tissue and organs that could be applied to artificial bone, muscle and blood vessels, and minute mechanisms such as nanomotors.

Group leader at the time, Tetsuya Tateishi (currently an Emeritus Researcher at AIST) described his stance as “Continuously creating new fields.” One of the good things about NAIR was the existence of opportunities to take on new challenges. It was a valuable presence in Japan, where innovation tended to be stifled.

An extremely long time was required to generate research results in the organism field. Research in the Bionic Design Project was continued at AIST in areas such as stem cell engineering technology, development of artificial organs, and innovative materials expressing nanolevel functionality.

## An environment that shifted ideas into action enabled world-leading research

It was obvious that the numerous successes delivered by NAIR could be attributed to the level of facilities and manpower that came with its abundant budget. However, this was not the only factor according to Emeritus Researcher Kazunobu Tanaka.

“A flexible management and research environment were in place to immediately verify through preliminary experiments whether an idea that came to mind would work or not. I was of the opinion that this was extremely important.”

This was indeed the case. The fact that researchers were not distracted by tasks other than their research and could devote themselves to their real work was significant. Further, the existence of a strong leadership group that played an active role in preparing such an environment was also substantial.

At the time, what emerged from interviews with researchers at NAIR was the image of highly proficient researchers throwing themselves into research based on ideas that they independently came up with. This most definitely led to world-beating achievements as teams and organizations were soundly deployed. The system employed at NAIR was revolutionary even for society as a whole at the time. Its achievements formed the roots of research at AIST today.

It is almost 15 years since AIST was established. Numerous innovative technologies have since been developed and contributed to society. Amid various limitations such as the social situation, expectations from industry, research talent and budgets, and research space, we hope that a management approach tailored to enable researchers to focus on research will continue to deliver excellent results that form cornerstones for future research and new industries.

## Bionic Design Project



▲ Group Leader Tetsuya Tateishi (at the time)



▲ Artificial manipulation of cell proliferation and differentiation functions.

**Leading the way AIST!**

**Spintronics: A fusion of electronics and magnetics**

**IT appliances with zero standby power:  
Is the dream close to reality?**

Shinji Yuasa

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**Humidity-regulating tiles: Spotlight on an eco-construction material**

**Potential as a construction material that regulates humidity as if it were breathing**

Masaki Maeda

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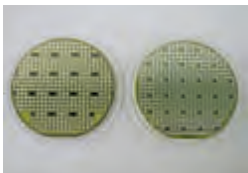


**Into the future AIST!**

**Semiconductor silicon carbide (SiC)**

**A revolution in power electronics made possible by semiconductor silicon carbide**

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**Development of commercial-scale production technology for single-wall carbon nanotubes**

**Great expectations for a dream material  
〈21<sup>st</sup> Century Industrial Revolution〉**

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**Personal care robots supporting an ageing society**

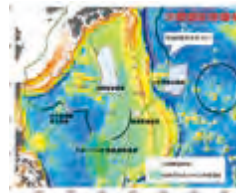
**Personal care robots spread out as a “new infrastructure”**

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Photograph: JQA

**AIST in present day living!**



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**Robot rises to the challenge of surveying an extreme environment unapproachable by humans**

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**The leading organization in Japan for metrological technology**

**The people and technology behind correct measurement, which is quite common nowadays**

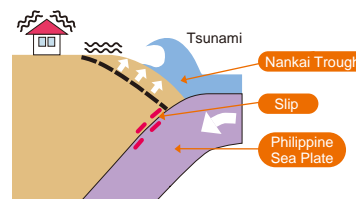
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Carbon fiber development process**

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**Leading the way AIST!**

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**A robust ceramic film can be realized without firing, merely through spraying!**

Jun Akedo

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**Claist: a high-performance clay-based thin film**

**A clay-based film boasting astounding gas barrier properties and heat resistance**

Takeo Ebina

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**AIST in present day living!**

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Photograph: Nikko

**Understanding music to bring out the true value of digital music**

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## From AIST to the Innovative World

Supporting, changing, and creating the future of life and society

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Asakawa Water Reclamation Center, Bureau of Sewerage, Tokyo Metropolitan Government (Pressurized fluidized bed sludge incinerator combined with turbocharger)

Kajima Corporation (Room door at Gunma Hospital)

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