理研百年

CENTENNIAL ISSUE

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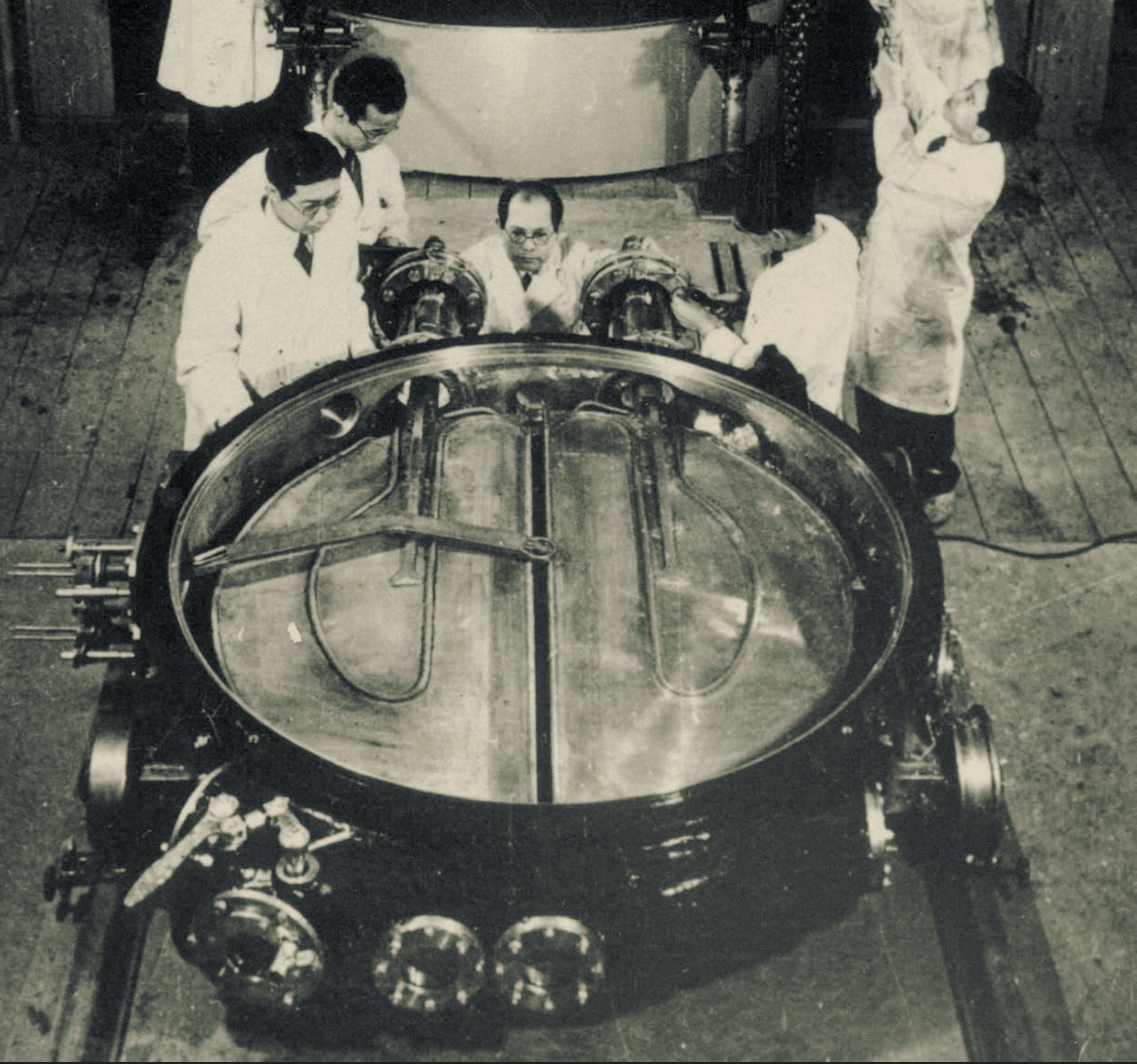
Special programs to support young researchers

The president of RIKEN on what the future holds

Special fold-out timeline



▲ **RIKEN's second cyclotron**
Yoshio Nishina (center) led the construction of a 200-ton cyclotron, which produced its first proton beam in 1944.

RIKEN, Japan's flagship research institute, conducts basic and applied experimental research in a wide range of science and technology fields including physics, chemistry, medical science, biology and engineering.

Initially established as a private research foundation in Tokyo in 1917, RIKEN became a National Research and Development Institute in 2015.

RIKEN Research is an online and print publication that highlights the best research published by RIKEN. This publication is a selection of the articles published by RIKEN at: **www.riken.jp/en/research/rikenresearch**

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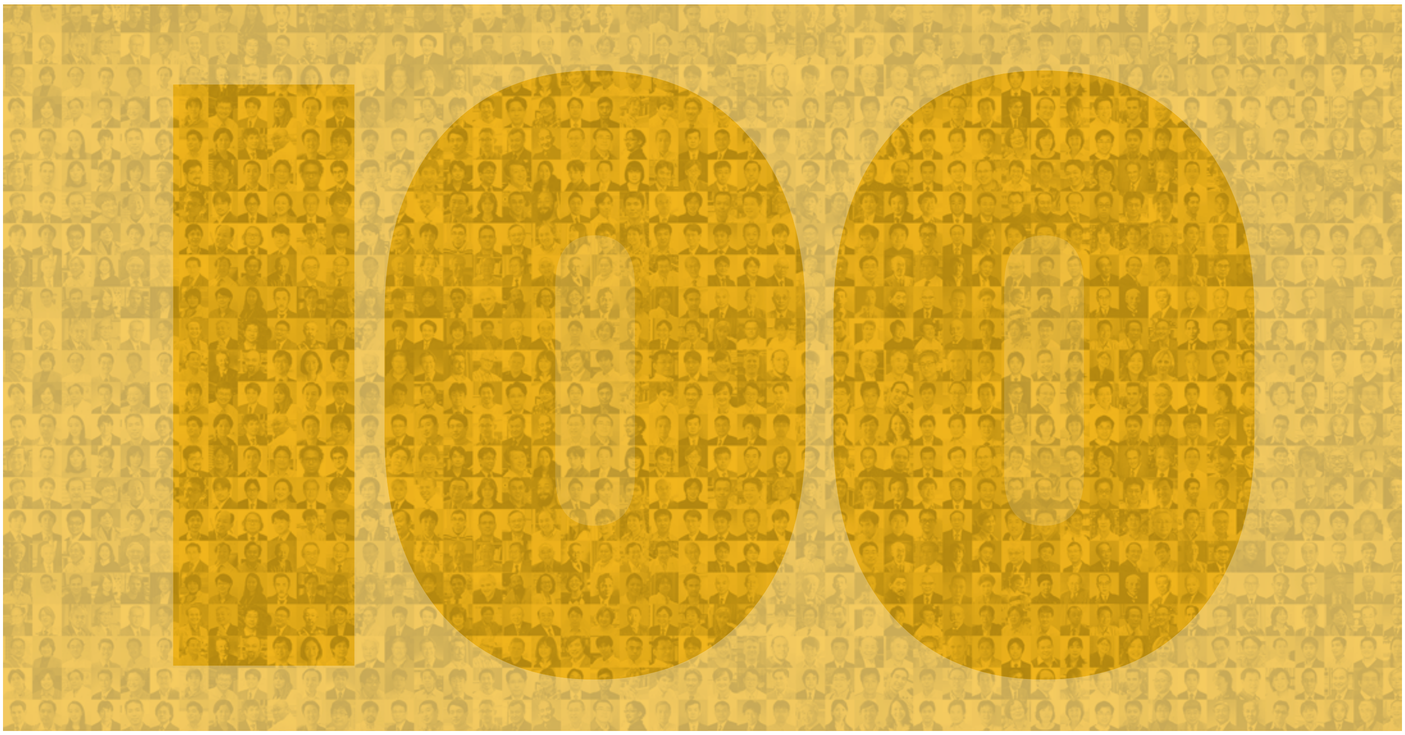


Putting curiosity to the use of society

This year, RIKEN celebrates its first one hundred years, and I would like to express our gratitude for the support we have received from society throughout our history. I think this is an appropriate time to look back to our founding principles and lay out our vision for the future.

One hundred years ago was a time when a clever man with a good idea could still make a dream reality. At that time, Japan had reached the end of the Meiji period and was embarking on its drive to westernize. It sent people abroad to learn from the West, and they returned with a conviction of the importance of science for improving the quality of life. One of these emissaries returned to Japan with the idea of establishing a Japanese scientific research institution. That idea became RIKEN.

The culture of innovation is what I most admire about the period when our institute was established. Take air-conditioning, for example. One hundred years ago, people felt cold and felt hot, and devised a way to control the temperature. I am concerned that today people don't seem to think as much about the future. We have become so comfortable that our impetus for a better life has been diminished.

Of course, the most powerful driving force for scientists is curiosity. Scientists like to pursue research that piques their curiosity, and as RIKEN moves into the future, I don't want to suppress that—rather, I want to encourage it. But scientists often say: "We have a discovery, is there any necessity?" It should be the reverse—necessity should drive curiosity. I believe that as a taxpayer-funded research organization, RIKEN should always be looking with one eye to what we can give back to the society that funds our work.

Science for innovation

By any measure, RIKEN has been a success in its 100-year history. Our organization successfully isolated vitamin A from cod oil, and made it available for the good of society. We invented enzyme-powered washing powders that are now used around the world. And we have spun off major companies such as Ricoh.

Currently, RIKEN is one of Japan's top research organizations. Our 2,000 or so working scientists produce around 2,400 papers a year. Of those papers, 5.6 per cent are gold standard, meaning that they are in the top 1 per cent of cited papers in a particular field. This is higher than any other Japanese research institute and compares favorably with overseas institutions that have staff and budgets many times RIKEN's size. We also know that our papers are often cited in patents taken out by other organizations, showing that our research is contributing to innovations in society.

It is for this reason that I find Masatoshi Okochi, a former director of RIKEN, so inspiring. He was very young—only 42—when he first became director in 1921 but he had a special talent for commercializing scientific results. Okochi separated RIKEN's work into two streams. One was for basic science in which he did not push researchers to think about applications of their work. The second was applications that were dealt with by specialists who knew industry and had good business sense. Okochi was very successful. He created 63 companies and he took the role of president in each company.

Passing the baton

I believe that collaboration is one of the keys to our success. During the Rio Olympics last year, I was struck by the 4 × 100 meter men's relay in which Japan won the silver medal. Individually, none of the Japanese runners were at the very top, but in this race, individuals need to cooperate to win. The baton passing was very skillful—a very smooth transition. That is why the Japanese team won a medal. Likewise in research and development, industry, research institutes and universities have to cooperate to win. The baton of scientific knowledge should be passed smoothly to industry and commercialization.

One of my important goals is to see RIKEN collaborating more closely with major Japanese companies. Many of them, including Toyota and Fujitsu, have basic research laboratories. But we know it is a costly part of their business. They want to reduce that cost but at the same time they would like to maintain their fundamental research sections somewhere. This is where RIKEN can step in. We could assume some of that role and they could share some of their R&D budget with us.

Through such steps, I hope to foster a culture of vision-based innovation within RIKEN. I define innovation as actions that change society for the better, not simply through economic growth. I am in the process of appointing what I tentatively call 'innovation designers'—people whose job is to identify social needs and convey these needs to the scientists working at RIKEN.

The United Nations' 17 Sustainable Development Goals, which were adopted in 2015, are a good starting point for ideas about how we can improve society by responding to the challenges that face humanity. We need to foster the mindset of connecting the researchers doing their own research, driven mostly by their own curiosity, to those issues, and I plan to encourage RIKEN researchers to do their work based on a vision of the future. I believe that most researchers will be able to do this, and as they do, we will be fulfilling our fundamental mission of being an institute that contributes, through leading-edge research, to the betterment of society. ■

Hiroshi Matsumoto
President, RIKEN

Reflections from around the world

Koji Omi

Founder and Chairman
Science and Technology in Society *forum* (STS *forum*)

Throughout the past century, RIKEN has made many breakthroughs that have contributed to the economy and daily lives. As a world leader, RIKEN is now conducting leading-edge research, and is also carrying out important collaborations with many international partners. I would like to offer RIKEN my warm congratulations on a hundred years of excellent scientific research, and express my hope that RIKEN will carry on its important work in the coming century.

The rapid progress of science and technology has brought tremendous benefits to the economy and our daily lives on the one hand. But on the other hand, advances in science and technology have also brought about issues such as global warming and a security crisis in information and communications technology. We call these the “lights and shadows” of science and technology. Science and technology is vital for solving these issues, which should not be dealt with only by professionals, but leaders in policy-making and business circles should also contribute to the solution from the long-term perspective of humanity. I firmly believe that the STS *forum* is playing a growing role in bringing together leaders in policy making, business and academia.

With its new status as a Designated National Research and Development Institute, RIKEN has a much more important mission to contribute to overcoming the many issues we face. RIKEN will fulfill such missions for the future of humanity. The STS *forum* and RIKEN share the common objective to contribute to the sustainable development of humanity and will accomplish this together.

Shinya Yamanaka

Director
Center for iPS Cell Research and Application (CiRA), Kyoto University

I was extremely humbled when asked to write in celebration of RIKEN’s 100th anniversary. Japanese scientists recognize RIKEN as the standard by which they judge their research.

RIKEN played an essential role in developing induced pluripotent stem (iPS) cells. When my research team was trying to reprogram somatic cells into the embryonic state, the FANTOM (Functional Annotation of the Mammalian Genome) database, built by RIKEN was a major tool for us to select 24 transcription factors as candidates that might induce pluripotency in somatic cells.

The institute has also been crucial to my dream of iPS cells reaching the clinic. When my team reported the generation of iPS cells, many researchers at RIKEN quickly began to explore the application of this new technology for therapies. RIKEN was an obvious choice when deciding who to collaborate with for the first iPS cell-based therapy in humans, with researchers at RIKEN taking the lead in conducting the transplantation.

I am certain that, as it has done over the past century, RIKEN will contribute to the most important scientific problems confronting the world. I hope that it will continue to take the initiative in working on not only cutting-edge research but also building scientific infrastructure like the FANTOM database for scientists to reach breakthrough discoveries.

Martin Stratmann

On the occasion of RIKEN's centennial, let me convey my cordial congratulations and best wishes for continued success and partnership for the next one hundred years! Indeed, the Max Planck Society highly treasures its close and long-standing cooperation with RIKEN, one of our key international and strategic partners. Just like the MPG's predecessor organization, the Kaiser Wilhelm Society, RIKEN was founded in the early 20th century. The two resembled each other in their organizational structure and their striving for research at the highest level. In 1984, RIKEN and MPG signed their first agreement on research cooperation. Since then, our partnership has steadily grown in a very fruitful way. The Max Planck Society and RIKEN have much in common in terms of research autonomy, international outlook, and the commitment to scientific excellence and evaluation.

President
Max Planck Society

A hallmark of our current scientific cooperation is the Max Planck–RIKEN Joint Center for Systems Chemical Biology. Due to the complementarity of research interests, the exchange of ideas and people, and its international visibility, the Joint Center stands out as an excellent example for successful German–Japanese science cooperation.

In cutting-edge research, global competition is becoming ever more intense, and international collaboration is now a major prerequisite for scientific success. RIKEN and the Max Planck Society are trusted partners who jointly contribute to scientific excellence. Looking into the future, we hope to continue the successful scientific collaborations of our institutes and to further strengthen the mobility of young researchers between Japan and Germany.

Chunli Bai

On behalf of the Chinese Academy of Sciences (CAS), I would like to offer my heartfelt congratulations to RIKEN for its 100th anniversary in 2017.

Since its founding in 1917, RIKEN has developed into the largest comprehensive research institution in Japan, renowned for its high-quality research in a diverse range of scientific disciplines and has made significant achievements in science and innovation. I wish RIKEN even greater success in the next century.

President
Chinese Academy of Sciences (CAS)

Since CAS and RIKEN signed a Memorandum of Understanding in 1982, both sides have enjoyed fruitful and friendly cooperative partnership. In the last 35 years, we have witnessed a particularly close and active collaboration, including frequent exchanges of visits, workshops, joint research projects and the establishment of joint labs, covering a wide range of areas.

As close neighbors, China and Japan face similar pressing challenges, such as an aging society, climate change, environmental protection and infectious diseases. CAS looks forward to strengthening the partnership with RIKEN to better confront these challenges. I hope our joint efforts will not only contribute to the advancement of science but also to the prosperity of both countries.

Science for all

For the past century, RIKEN has championed robust science for a stronger economy and a healthier society

Yoshio Nishina's laboratory at RIKEN constructed Japan's first cyclotron in 1937, and its second in 1944 (pictured).

In the summer of 1913, 120 influential industrialists and government officials gathered at the exclusive Seiyoken restaurant in Tokyo at the behest of Eiichi Shibusawa, a prominent Japanese banker and businessman. While the menu boasted some of the most highly praised curries and potato croquettes in Imperial Japan, the real focus of the evening was a speech by Jokichi Takamine. A millionaire scientist, Takamine had an important message that Shibusawa wanted the guests to hear—the world was moving away from manufacturing industries and toward enterprises built on the physical and chemical sciences. Japan, he urged, needed to establish a research institute dedicated to basic science that could compete with similar facilities in Germany, France and the United States.

The Institute of Physical and Chemical Research, also known as RIKEN, was established on 20 March 1917, with Prince Fushimi Sadanaru as president and mathematician Dairoku Kikuchi as director. "To turn the country from imitation to creative power, there is no alternative but to promote research in pure physics and chemistry," wrote Shibusawa in an article several months later. The institute was set up as a private foundation with two million yen of donations from wealthy individuals as well as some government support. It was modeled after the Kaiser Wilhelm Association, the predecessor of the Max Planck Society, and split into two independent research divisions—one for chemistry and one for physics.

Shibusawa had grand plans for RIKEN, but the export boom of the First World War was soon stymied by Japan's post-war financial instability. The institute scraped by on limited funds until another visionary business executive inherited the project.

Science-driven economy

Masatoshi Okochi had radical ideas and the wherewithal to implement them. The son of a feudal lord, Okochi was a shipbuilding engineer before joining RIKEN in 1918 as a researcher. Three years later, when only 42, he was appointed director. Within a year, he abolished the rigid hierarchies and entrenched divisions of the physics and chemistry sections. Laboratory heads were given complete autonomy over their research, staff and budgets, and were encouraged to collaborate across disciplines. The reformed environment was "a paradise for scientists," said Shinichiro Tomonaga, who worked in nuclear physicist Yoshio Nishina's laboratory and went on to win the Nobel Prize in Physics 1965 for his work on quantum electrodynamics.

Okochi strongly believed in employing science to bolster the national economy and then reinvesting the profits into research. Under this scenario, industry would act as the face of science and its biggest cheerleader. To this end, Okochi established the RIKEN Konzern, a group of spin-off companies with himself as president. The companies commercialized patents registered by RIKEN researchers, and the financial gains supported further research at the institute. By 1937, over 60 per cent of RIKEN's income came from the Konzern, which by 1939 had leverage over 63 companies. Blockbuster sales of piston rings, vitamin A and sensitized paper were fodder for fundamental science at RIKEN. "In the final analysis, future wars will not be wars of military might versus military might," wrote Okochi in 1937. "They will be wars involving the entire nation's scientific knowledge and industrial capacity."

The scientists that presided over these new laboratories would emerge as leaders in the Japanese scientific community. One of them was Hantaro Nagaoka, director of RIKEN's Physics Division. Nagaoka's pioneering work, from theoretical and atomic physics to experimental physics, geophysics and magnetism, paved the way for Japan's later achievements in these fields. Likewise, Nagaoka's junior colleague Kotaro Honda, a physicist specializing in metallurgy and magnetism, raised the profile of Japanese magnetism research to an international level as head of the RIKEN–Honda Laboratory at Tohoku Imperial University, the first in a long line of RIKEN laboratories operated through collaborations with universities.

Agricultural chemist Umetaro Suzuki, another of RIKEN's founding scientists, is known today as the father of vitamin research in Japan. His most important achievement was the isolation of vitamin B_1 from rice bran, which proved to be an effective cure for a debilitating disease known as beriberi. These three prominent researchers are known as RIKEN's three 'Taros'—Hantaro, Kotaro and Umetaro.

Battle for survival

In December 1941, Japan entered World War II with attacks against American and British holdings in the Pacific. RIKEN was conscripted into the war effort and ordered to attempt to build an atomic bomb. In 1937, Nishina's well-staffed laboratory had already constructed Japan's first cyclotron, weighing more than 20 tons, for accelerating charged particles. In 1943, they finished construction of a second cyclotron, twice the size and ten times the weight. While one goal was to use these accelerators for the uranium enrichment project, the facilities were destroyed in American air raids in the closing months of the war. On 15 August 1945, the war ended. The occupying forces, led by General Douglas MacArthur, dumped Nishina's cyclotrons into the sea and were prepared to dissolve the entire research institute.

This time, RIKEN was rescued by a close friendship between Nishina and American physicist, Harry Kelly, who served as science advisor to MacArthur. Nishina was appointed president of RIKEN in 1946, and, with Kelly's help, registered it as the private company KAKEN, the Scientific Research Institute Ltd., in 1948. Nishina kept the company afloat by downsizing, securing bank loans, licensing discoveries and selling pharmaceuticals (including the antibiotic penicillin).

The new company was tasked with helping to rebuild Japan from the ravages of war. "As scientists and engineers, it is our duty to make earnest efforts to revitalize industry," wrote Nishina in 1946. The company, and the country, gradually recovered. In 1949, Hideki Yukawa, a former student of Nishina's, became Japan's first Nobel laureate, being awarded the Nobel Prize in Physics for his prediction of the existence of subatomic particles known as mesons. And in 1958, RIKEN regained its name and was recognized as a public corporation. In 1967, RIKEN relocated to a large plot of state-owned land in Wako city on the outskirts of the capital.

Blockbuster sales of vitamin A, bottled as RIKEN Vitamin, funded basic research at RIKEN in the 1930s.

Innovation driver

Following that difficult time, RIKEN began a new period of progress, international collaboration and breakthrough science. From its base near Tokyo, RIKEN expanded to other locations across the country: Tsukuba, Yokohama, Kobe and Harima. At each site, it set up research centers dedicated to specific areas of research: emergent materials science, photonics, sustainable resource science, nuclear physics, bioresources, genomics, medical and life sciences, developmental biology, supercomputing, quantitative biology and synchrotron science. In time, these centers captivated the world with their achievements, from helping to decode the entire human genome, to constructing an x-ray free-electron laser next to a synchrotron-radiation facility, developing the world's fastest supercomputer—the K computer—launching the first clinical study using induced pluripotent stem (iPS) cells and discovering the new element nihonium.

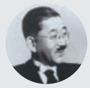
In 2003, RIKEN became an Independent Administrative Institution under the Japanese Ministry of Education, Culture, Sports, Science and Technology. This designation was given to government bodies that served an important national function, but needed the freedom to manage their own operations with some autonomy. Ryoji Noyori, winner of the 2001 Nobel Prize in Chemistry, stepped up as president. In 2015, RIKEN was reorganized into a National Research and Development Institute, with the aim of creating cutting-edge science as well as disseminating and applying the results for public benefit. This change coincided with the nomination of Hiroshi Matsumoto as president of RIKEN.

RIKEN acquired its latest status on 1 October 2016 when it became a Designated National Research and Development Institute. This new status requires RIKEN to take a leading role in Japan's innovation system, forging ties between industry and academia. It is also tasked with supporting the government in realizing its policies. RIKEN's role as a beacon of science and a driver of social and industrial change is now more valuable than ever. ■

RIKEN presidents


1917
Dairoku Kikuchi


1917–1921
Koi Furuichi


1921–1946
Masatoshi Okochi


1946–1951
Yoshio Nishina


1951–1952
Kiichi Sakatani


1952–1956
Takeshi Murayama


1956–1958
Masanori Sato


1958–1966
Haruo Nagaoka


1966–1970
Shiro Akahori


1970–1975
Toshio Hoshino


1975–1980
Shinji Fukui

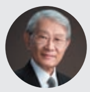

1980–1988
Tatsuoki Miyajima


1988–1993
Minoru Oda


1993–1998
Akito Arima


1998–2003
Shunichi Kobayashi


2003–2015
Ryoji Noyori


2015–present
Hiroshi Matsumoto

RIKEN through the century

1924

Born in 1884 in Kyushu, Chika Kuroda studied science and became a teacher. When Tohoku University opened its doors to female students in 1913, for the first time in Japan, she joined the chemistry department. In 1916, Kuroda became the first woman in the country to receive a bachelor of science. She joined Riko Majima's organic chemistry laboratory at RIKEN in 1924, where she determined the molecular structure of the purple pigment in gromwells. She later characterized the natural red pigment in safflowers and extracted the yellow crystals in onion peel, which led to the development of a treatment for high blood pressure. Kuroda retired as a professor at Ochanomizu Women's University in 1952 and received the Medal with Purple Ribbon in 1959 for her accomplishments.

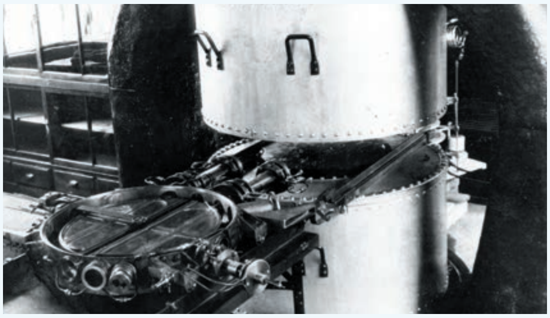
1937

Japan's first cyclotron, built by Yoshio Nishina in 1937, laid the foundation for nuclear physics research in the country. It was the first cyclotron built outside of the United States, weighing 20 tons. But even before it began accelerating particles, Nishina made plans to build a larger cyclotron with a 200-ton magnet. Both projects were funded by the Japanese government and a private foundation. Over the past century, RIKEN has built nine cyclotrons. Its latest superconducting ring cyclotron is the world's most powerful accelerator, weighing 8.3 million kilograms and boasting a maximum beam speed of 70 per cent the speed of light.

2002

In 1962, biochemist Osamu Shimomura extracted green fluorescent protein (GFP) from the glowing jellyfish *Aequorea victoria*, earning him the 2008 Nobel Prize in Chemistry. The protein, together with advances in fluorescence microscopy, enabled the imaging of molecular phenomena in living organisms. In 2002, Atsushi Miyawaki's laboratory at the RIKEN Brain Science Institute significantly contributed to the field by developing new fluorescent proteins, Kaede—discovered in stony coral—and Venus. In 2011, the group made a further breakthrough in imaging by creating the aqueous clearing agent, Scale*S*, that makes fixed tissues transparent. RIKEN has since advanced clearing technology with solutions such as SeeDB, CUBIC and Scale*S*.

Chika Kuroda, Japan's first female bachelor of science graduate.



Japan's first cyclotron, built by Yoshio Nishina in 1937, laid the foundation for nuclear physics in the country.

1917
RIKEN, known at the time as the Institute of Physical and Chemical Research, is founded

1921
Scientist and businessman Masatoshi Okochi becomes RIKEN's third president

1922
RIKEN develops Adsole, which was used for air conditioners

1924
Japan's first female bachelor of science graduate, chemist Chika Kuroda, joins RIKEN

1925
RIKEN scientists invent almite, used to coat aluminum for strong kitchenware, and in *Maki-e*, traditional Japanese lacquer artwork

1926
Keiichi Ebihara invents a method for manufacturing uniform piston rings

1927
RIKEN's subsidiary companies, the RIKEN Konzern, launch with Rikagaku Kogyo

1934
Physicist Kotaro Honda, inventor of magnetic KS steel, develops New KS Steel

1936
The predecessor of today's Ricoh is formed to sell positive sensitized paper

1937
Nuclear physicist Yoshio Nishina constructs a cyclotron, the first outside the United States

1948
RIKEN reemerges after World War II as a private company named KAKEN, the Scientific Research Institute Ltd.

1958
KAKEN becomes a public corporation and is renamed RIKEN

2003

On 14 April 2003, the International Human Genome Sequencing Consortium announced the completion of the Human Genome Project, a decade-long initiative culminating in the complete sequence of the 3-billion-letter human genome. Researchers led by Yoshiyuki Sakaki at the former RIKEN Genomic Sciences Center contributed by leading the sequencing of chromosomes 21 and 11, and acting as the sub-lead for chromosome 18. In May 2000, the results for chromosome 21 were published in *Nature*—of global interest because an extra copy of the chromosome causes Down's syndrome. The paper suggested that the human genome may contain only about 40,000 genes, much fewer than previous estimates of up to 100,000. The RIKEN team sequenced the entire chimpanzee genome in 2000 and found that humans share close to 99 per cent of our genes with chimpanzees.

Members of the RIKEN-led consortium Functional Annotation of the Mammalian Genome (FANTOM) at a meeting at RIKEN's Yokohama campus.

2005

In 2001, the RIKEN-led international consortium Functional Annotation of the Mammalian Genome (FANTOM) published its first database of 21,076 complementary DNAs in the mouse genome. The project sought to use this library to link RNA transcripts with their corresponding protein products. The goal was to determine all the genes encoded by the enigmatic string of nucleotides, and, eventually, even their function. FANTOM3 revealed in 2005 that more than 63 per cent of the mouse genome is transcribed into RNA. Hidden in these transcripts is a wide 'desert' of non-coding RNAs (ncRNAs) that do not encode proteins. The FANTOM consortium, now in its sixth iteration, has expanded its analysis from the mouse to the human, comparing transcription in different cell types and tissues and elucidating the unknown functions of ncRNAs.

The International HapMap Project published a haplotype map of the human genome with more than one million single nucleotide polymorphisms (SNPs) obtained from 269 DNA samples from 4 populations. The former RIKEN SNP Research Center, led by Yusuke Nakamura, contributed 24.3 per cent of the map—the largest contribution by any single member of the participating institutions.

2006

The Golgi apparatus is the sorting center of the cell, where proteins are processed for distribution throughout the cell. Before Akihiko Nakano settled the debate, researchers were uncertain about how this cargo was transported from one end to the other end of the Golgi. Nakano developed an imaging technique using fluorescent probes and light microscopy to get a live stream into yeast cells, only to find a

1987
Kao Corporation launches Attack, a laundry detergent produced using alkaliphilic bacteria discovered by Koki Horikoshi

1990
Hitoshi Ohmori and Takeo Nakagawa develop a highly efficient process for grinding ceramics

1993
A Japanese chemical manufacturer launches the environmentally friendly pesticide Kaligreen, developed by Yutaka Arimoto

1995
Meiji Dairies launches VAAM, a sports drink containing an amino acid formula that Takashi Abe isolated from hornets

1997
Inauguration of the SPring-8 synchrotron radiation facility at Harima

2000
Masashi Miyano's team determines the structure of rhodopsin, an important protein in visual processing

2001
Mutant plants bred by Tomoko Abe using RIKEN's heavy-ion accelerator are put on the Japanese market

2002
- Yousoo Kim and Maki Kawai use scanning tunneling microscopy to study single molecules on solid surfaces
- Atsushi Miyawaki and colleagues improve real-time molecular imaging by developing Kaede and Venus fluorescent proteins

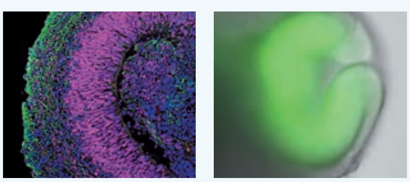
2003
- Jaw-Shen Tsai helps lay the basis for quantum computers with coherent quantum logic operation of superconducting quantum states
- RIKEN is reorganized into an Independent Administrative Institution under the Japanese Ministry of Education, Culture, Sports, Science and Technology

colorful three-dimensional display. Instead of passing the cargo through its different compartments, the Golgi's ribbed structures act like a conveyor belt, moving the luggage along with them. Nakano has since used the advanced imaging system to gain a clearer picture of the process.

2007

When a plant is just a little shoot, its apices are filled with the possibility of becoming a leaf, a stem or even a flower. This growth is controlled by a series of biochemical reactions involving plant hormones called cytokinins. In 2007, Hitoshi Sakakibara identified an enzyme in the swelling tips that controls cytokinin activity and plant growth. The enzyme was known as LONELY GUY, or LOG. LOG genes can trigger cytokinin synthesis in almost all developing plant tissues and organs. Sakakibara's work continues to reveal ways in which cytokinins are regulated.

2008



Cerebral cortical tissue (left) and an optic cup (right) derived from embryonic stem cells by Yoshiki Sasai.

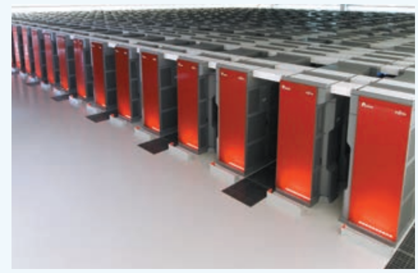
In 2008, a team led by Yoshiki Sasai at the RIKEN Center for Developmental Biology generated the first three-dimensional mini-brain in a dish. The structures formed spontaneously from mouse embryonic stem cells into tiny balls representing the outer layer of the brain. His team went on to create rudimentary pituitary glands as well as optic cups with large, curved structures containing the rod- and cone-shaped photoreceptors found in the retina.

2010

A decade after publishing the first draft human genome, a team at the former RIKEN Center for Genomic Medicine assembled the whole genome of a Japanese individual using cutting-edge sequencing technology. Comparing the variation in the Japanese genome with those of six other individuals from around the world, they found many new variations. This revealed a wealth of genetic diversity in the human genome and confirmed the utility of whole-genome sequencing for understanding this diversity in various populations.

2011

RIKEN and Fujitsu partnered in 2006 to develop a next-generation supercomputer that could perform more than 10 petaflops of operations per second, named after the Japanese word for 10 quadrillions,



The RIKEN K computer was ranked the world's fastest supercomputer in 2011.

kei. In 2011, the K computer was ranked the world's fastest supercomputer in the TOP500 list, maintaining its position for a year. Significant improvements to the computer's system performance named it first in the HPCG benchmark in 2016 for its speed in solving the type of problems encountered in industrial and scientific applications. An international team, including RIKEN researchers, reached the top spot in a new ranking for data-intensive processing prowess—Graph 500—which it has held for the past two years. The K computer has played a central role in a broad range of fields, from drug discovery to space science.

2012

Construction of SACLA, the world's second x-ray free-electron laser (XFEL), was completed in March 2011. On 7 June 2011, SACLA generated a

2005
- The FANTOM3 consortium discovers that a staggering percentage of the mouse genome contains noncoding RNA
- The International HapMap Project publishes a haplotype map of the human genome

2006
- Akihiko Nakano settles the debate over how the Golgi apparatus packages and transports cargo
- Toyoki Kunitake synthesizes strong and flexible, freestanding nanomembranes

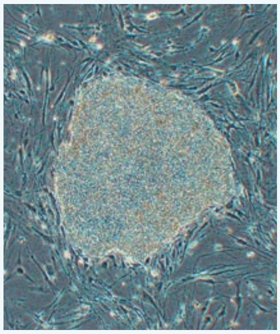
2007
- Hitoshi Sakakibara identifies an enzyme that controls plant growth
- Hiroki Ueda discovers the gene and cell network regulating mammalian clocks
- Minoru Yoshida finds the first inhibitor of messenger RNA splicing, which could lead to new cancer treatments
- Hideki Hirayama makes deep-UV LEDs, useful for water purification
- Completion of the RI Beam Factory allows the exploration of exotic, neutron-rich isotopes, including the discovery of 45 rare isotopes

2008
Yoshiki Sasai's group induces embryonic stem cells to spontaneously form 3D brain tissue

2009
Kazuo Shinozaki discovers how the plant hormone abscisic acid coordinates a plant's response to environmental stress

2010
- Yasunori Yamazaki traps and manipulates antihydrogen atoms for the first time
- RIKEN sequences the genome of a Japanese individual
- RIKEN and the Brookhaven National Laboratory partner to study the temperature of the early Universe
- Katsumi Midorikawa generates intense attosecond pulses of light for nonlinear optical experiments

The Detector Array for Low Intensity Radiation 2 at the RI Beam Factory was used to uncover a new 'magic' number.



Human induced pluripotent stem cells.

hard-x-ray laser at a wavelength of 1.2 angstroms—the shortest wavelength for FELs at the time. SACLA was formally inaugurated in March 2012 with the start of operation for users. Ultrabrilliant XFEL light from SACLA has enabled the observation of ultrafast reactions involving atoms and electrons in functional materials, and has extended the frontiers of chemical, biological, physical and optical sciences. For example, SACLA is elucidating unexplored chemical reactions in photosynthesis, which could help to achieve global sustainability. Investigation of quantum x-ray optics using SACLA could establish a new theoretical framework in fundamental physics. SACLA also spurs innovation through partnerships between industry and academia.

2013

When the nucleus of an atom contains just the right number of protons or neutrons, it gains an unusual stability. Physicists have discovered numerous such 'magic' numbers in stable nuclei. In 2013, Hiroyoshi Sakurai and David Steppenbeck studied the exotic radioactive calcium isotope ^{54}Ca at the RI Beam Factory and observed a new magic number—34. Studying how such nuclear magic numbers appear and disappear in highly unstable nuclei can help us to understand how stars evolve.

2014

A team led by Masayo Takahashi of the RIKEN Center for Developmental Biology transplanted retinal tissue developed from induced pluripotent stem (iPS) cells cultured from a female patient's own cells back into her body, in the world's first clinical study involving iPS cells. The successful surgery, which targeted age-related macular degeneration, a major cause of vision loss in the elderly, sought to gauge the safety of iPS cell therapy.

2016

On 30 November 2016, the International Union of Pure and Applied Chemistry (IUPAC) officially announced that element 113 would be named nihonium (symbol Nh). It was first synthesized by Kosuke Morita's group at the RIKEN Nishina Center for Accelerator-Based Science in 2004, and again in 2005 and 2012. In 2015, the IUPAC recognized RIKEN's discovery and awarded the group the right to name the new element. It is the first element to be named by an institute in Asia.

RIKEN announced that it would become the first country in Asia to name an element at a press conference on 1 December 2016.

2011

The K computer is ranked the world's most powerful computer in the TOP 500 List

2012

- Inauguration of the SACLA XFEL facility in Harima
- Naoko Imamoto names Hikeshi, a nuclear transport protein that becomes active under heat stress
- Susumu Tonegawa shows that memories can be implanted and erased by activating neurons with light to reveal how the brain stores and recalls experiences
- Tahei Tahara clarifies the structure and properties of water on surfaces such as biological membranes

2013

- Naoto Nagaosa and Yoshinori Tokura describe skyrmions, nanoscale swirling magnetic textures, providing the basis for highly efficient spintronic devices at room temperature
- RI Beam Factory researchers uncover a new nuclear magic number—34

2014

- Masayo Takahashi leads the first transplant of tissue derived from iPS cells
- Takaomi Saido reproduces plaque formation and memory loss in a mouse model of Alzheimer's disease

2015

- Hidetoshi Katori synchronizes two optical lattice clocks with 18-digit precision
- The government designates RIKEN a National Research and Development Institute

2016

- Masanori Murayama shows that deep sleep is important for retaining memories
- Element 113, discovered by Kosuke Morita's group, is named nihonium (Nh)
- RIKEN becomes a Designated National Research and Development Institute
- Stefan Ulmer determines the magnetic moment of an antiproton with high precision

A big science family

Collaboration at RIKEN transcends physical and institutional boundaries, and prospers from cutting-edge facilities available to researchers of all disciplines

The K computer is a top-ranked supercomputer that supports collaborative research in many fields.

The RIKEN S
tron laser (S

In-vacuum undulators at the SPring-8 Angstrom Compact free electron LAser (SACLA).

The superco
8,300 tons.

What do big-data scientists, meteorologists and electrical engineers have in common? What about nanoscientists, rubber experts and a tire company? They all use RIKEN's cutting-edge facilities. RIKEN fosters collaboration by operating publically accessible, state-of-the-art equipment, bringing divergent strands of science under a single roof and reinforcing strong partnerships across geographic and corporate boundaries.

Facilities firsts

Scientists of all backgrounds have access to a wide selection of tools at RIKEN. Maintaining the tradition of accelerator-based science started by Yoshio Nishina, RIKEN's premier heavy-ion accelerator facility, completed in Wako in 2006, delivers intense radioactive-isotope beams to explore new areas of nuclear physics, and for applied science projects such as plant breeding.

At the Nuclear Magnetic Resonance (NMR) Facility in Yokohama, scientists use powerful magnetic fields to explore the structure of proteins and inorganic materials, while at the Genome Network Analysis Support Facility they perform gene expression analysis and genomic sequencing using high-throughput sequencers. The molecular imaging center in Kobe is a playground for biologists keen to explore the movements of molecules in the body.

The RIKEN SPring-8 Center in Harima is the only place in the world to offer an x-ray free electron laser (SACLA) and a synchrotron radiation (SPring-8) facility at the same location, bringing innovation to observation. And the RIKEN BioResource Center in Tsukuba stores a wide range of living strains of experimental mice, plants, cell lines, genetic clones and microbes, which it delivers to researchers worldwide. The collection includes human induced pluripotent stem-cell lines developed by Nobel laureate Shinya Yamanaka.

The computational resources of the K computer have supported hundreds of publications on every subject imaginable, from life science to weather forecasting, manufacturing, disaster reduction and space science. Around 30 per cent of the K computer's users are from industry. The post-K computer is under development, and promises to be even more useful for tomorrow's researchers, manufacturers and energy leaders.

Intermingling

It is not just RIKEN's intriguing facilities that get scientists mixing and mingling—goal-oriented interdisciplinary centers give researchers along the scientific spectrum cause to

Pring-8 Center is the only place globally to have both an x-ray free-elec-
ACLA) and a third-generation synchrotron radiation (SPring-8) facility.

nducting ring cyclotron at the RI Beam Factory in Wako weighs

Liquid-nitrogen tanks preserve valuable biological materials at the RIKEN BioResource Center in Tsukuba.

The RIKEN Yokohama campus houses a powerful nuclear magnetic resonance facility (photo) and three life sciences research centers.

In 2016, RIKEN signed a comprehensive research agreement with Kazan Federal University in Russia.

RIKEN Center for Emergent Matter Science researchers combine work in physics, chemistry and electronics in a quest to develop new devices and technologies.

The RIKEN Integrated Innovation Building at Kobe's Port Island hosts teams involved in collaborative research with industry.

The RIKEN-RAL Muon Facility in Oxfordshire, United Kingdom.

communicate. The RIKEN Center for Sustainable Resource Science unites plant scientists, chemists and chemical biologists in a noble goal to create environmentally friendly natural resources and energy for a sustainable global society.

Meanwhile, researchers at the RIKEN Center for Emergent Matter Science use the combined forces of physics, chemistry and electronics to build a sustainable society and develop more efficient technologies to reduce energy consumption and the burden on the environment.

The RIKEN Interdisciplinary Theoretical Science Research Group, launched in 2013, has theorists contemplating questions as diverse as the formation of black holes and chromosome organization and segregation.

In addition, the RIKEN Cluster for Industry Partnerships facilitates the relationship between RIKEN researchers, the private sector and other research institutions, applying RIKEN's expertise and technology toward developing innovative and useful products and applications.

The RIKEN Center for Advanced Intelligence Project was established in 2016. It mainly conducts fundamental research in artificial intelligence, including mathematical research and social research, in addition to applying such fundamental technologies to accelerating scientific research and solving real-world problems.

Mapped out

RIKEN's collaborators are scattered around the world. The institute has signed research agreements with more than 400 organizations in 53 countries and regions, as well as establishing joint labs from Germany to Russia and China.

Among the most well-established are the RIKEN BNL Research Center in New York, which is pursuing the existential question of how matter formed in the early Universe, the RIKEN–MIT Center for Neural Circuit Genetics in Massachusetts, which is trying to determine the neural basis of learning and memory, and the RIKEN–RAL Muon Facility in Oxfordshire, which is probing the properties of materials using beams of charged subatomic particles known as muons.

RIKEN has been a leader or key partner in a number of international consortiums including FANTOM (Functional Annotation of the Mammalian Genome), the International Cancer Genome Consortium and the Human HapMap Project.

With the adoption in 2015 of the RIKEN Initiative for Scientific Excellence, which calls for RIKEN to become a global hub for science and technology, RIKEN is poised for greater advances in the next 100 years.

Nurturing talent and creativity

RIKEN offers a number of programs designed to support promising young researchers

RIKEN is committed to providing as much support as possible to young researchers, from both home and abroad. The Special Postdoctoral Researcher (SPDR) program gives young and creative scientists the opportunity to take on autonomous research under the direction of their host laboratory's principal investigator. This program, which has been running for more than 25 years, provides up to three years of funding, subject to annual reviews, and helps promising scientists establish global careers.

RIKEN offers doctoral candidates the chance to further their studies as International Program Associates (IPA) or Junior Research Associates (JRA) under the supervision of a senior RIKEN scientist.

Students enrolled or about to enroll in a PhD at one of the many domestic and overseas universities participating in RIKEN's Joint Graduate School Program are eligible to apply for the IPA program, while candidates for the JRA program must be enrolled or scheduled to be enrolled in a doctorate course at a Japanese graduate school at the time of employment.

The RIKEN Hakubi Fellows Program, a system for fostering the development of world-class young leaders in scientific research, will be launched soon.

In addition to these programs, RIKEN operates several summer schools that give junior scientists and students the opportunity to learn from eminent researchers.

To find out more, please visit:
www.riken.jp/en/careers/programs/
Or contact: pr@riken.jp

NAOHITO SAITO

Director
J-PARC (Japan Proton Accelerator Research Complex)

I was a special postdoctoral researcher at RIKEN for 11 months in 1995. During that period, and for more than a decade after, I had the opportunity to work on the Relativistic Heavy Ion Collider Spin Project, an international collaboration at Brookhaven National Laboratory in the United States. I fully enjoyed RIKEN's free and versatile research environment. Its frontier spirit in diverse fields still forms the foundation of my research.

KIMIKO SEKIGUCHI

Associate Professor of Nuclear Physics
Department of Physics,
Tohoku University

The time I spent as a special postdoctoral researcher at RIKEN was formative in establishing my research style. I really enjoyed studying nuclear physics using the world-class accelerator at the RIKEN Accelerator Research Facility, the predecessor to the RI Beam Factory. I am very proud to have been a member of the facility, and to continue to have opportunities to conduct experiments there. Happy 100th anniversary to RIKEN!

SUDESH KUMAR

Professor of Microbiology and Biotechnology
School of Biological Sciences,
Universiti Sains Malaysia

My six years at RIKEN, first as a PhD student and then as a special postdoctoral researcher, exposed me to many research activities and people in Japan and abroad. RIKEN truly is a melting pot of different research cultures. I am fortunate to be still connected to RIKEN through various research collaborations. On RIKEN's 100th year celebration, I wish that RIKEN will continue to flourish as a premier research institute.

Encouraging a long-term perspective

RIKEN Executive Director Shigeo Koyasu discusses how RIKEN is working to provide the optimum environment for scientists to excel

› How important is a stable working environment for producing great science?

To succeed in science, we need to work on projects that require long time frames. For projects with relatively short time frames, scientists typically write a paper and then get a new position and repeat the cycle. Sending out bright researchers to other scientific organizations is beneficial for science in some ways, but for RIKEN to grow stronger, we need more researchers either with permanent positions or with relatively permanent positions, which we call indefinite-term employees. Therefore, we recently revised our personnel rules to enable us to hire more indefinite-term researchers. These research staff have a secure job until the age of 60, with an optional five-year extension, which allows them to focus on more-long-term goals. We are aiming to increase the proportion of RIKEN research staff on these indefinite-term or permanent contracts from the current 10 per cent up to about 30–40 per cent.

› Why do you see long-term contracts as being essential?

To tackle very difficult problems. Addressing some of the United Nations' Sustainable Development Goals, for example, will require a long-term view. You can't achieve a goal that takes a decade to solve if you have a five-year limit. The time constraint makes researchers reluctant to tackle the big challenges. A good example is our synthesis of element 113, which has now officially been named nihonium (symbol Nh). It took 20 years to achieve that goal. Certain projects require a long-term view and effort. At RIKEN, we believe this is important.

› People talk a lot about collaboration. How does RIKEN foster internal collaboration?

We recently launched several interdisciplinary, RIKEN-wide projects. For example, we wanted to tackle the problems associated with an aging society, so we put a call out to see who wanted to join the project from across the institute. This enabled us to connect people within RIKEN—researchers at Wako, Yokohama, Kobe and our other campuses. The project is not limited to biologists—engineers, physicists and chemists can also join. This kind of top-down approach combined with bottom-up proposals could help researchers to realize that working with others might not be so bad and could generate synergistic new fields.

› Is this a new approach?

Not quite so new. When I became director of the RIKEN Center for Integrative Medical Sciences in Yokohama in 2014, I asked all the principal investigators to give me 30 per cent of their time to tackle a problem together, such as type 2 diabetes and atopic dermatitis. I believe the collaboration was a success. I'd like to expand this kind of approach RIKEN wide. Even with a limited budget, we can achieve a lot. And we could even expand this approach to include researchers at universities or in industry.

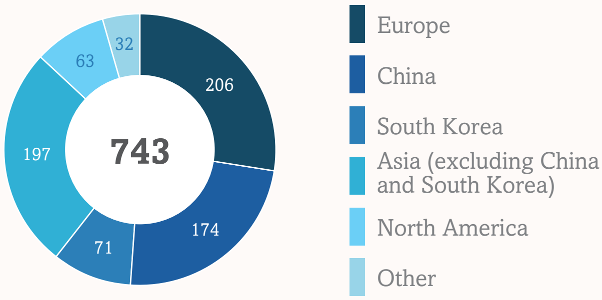
› President Matsumoto has proposed 'innovation designers' to suggest problems for scientists to solve. How will they work with RIKEN's existing advisory councils?

We've yet to determine where these innovation designers fit within the current RIKEN structure. We are still searching for candidates and clarifying how to proceed with those discussions. But I think it is important to give them lots of freedom to propose new ideas. They should not be obliged to realize these ideas. It is important to give them the freedom to think and advise. We plan to implement this proposal by April 2017.

Global research impact

International faculty and staff*

In 2016, RIKEN employed 3,426 individuals, including nearly 2,000 researchers. The number of international researchers has risen significantly in the past ten years; they now account for about 18 per cent of researchers at RIKEN.



*Includes scientists, visiting scholars, students, technicians and administrative staff

Research output

The number of papers published by RIKEN has dramatically increased since 1980. In the last decade alone, around 2,500 papers have been published every year in a wide range of fields. Of the papers published in 2014, 5.6 per cent were 'gold standard' papers in the top 1 per cent of papers cited in their field, and 28.3 per cent were in the top 10 per cent of cited papers.

2,591 papers published in 2015

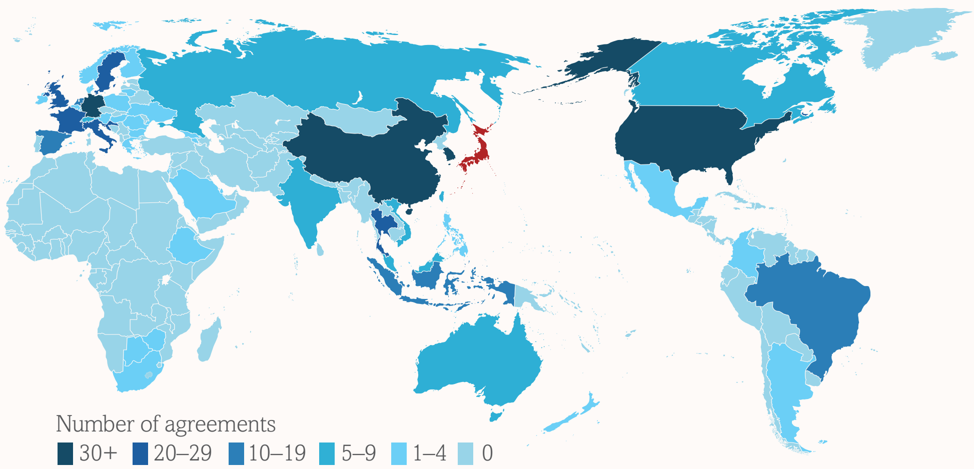
28.3% ranked in the top 10% of cited papers

5.6% ranked in the top 1% of cited papers

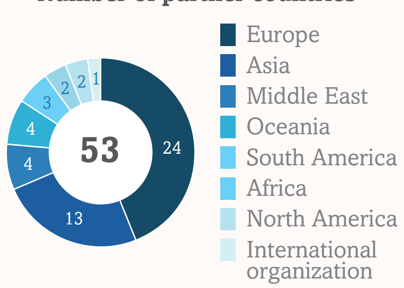
Source:
Clarivate Analytics' Web of Science, Science Citation Index Expanded, 8 June 2016

International research partners

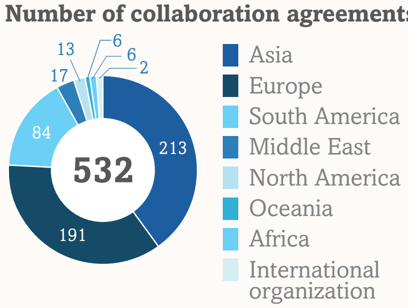
As RIKEN continues to grow, so does its network of collaborators at research institutes around the world. RIKEN actively supports research collaborations and the exchange of researchers, students and staff with universities and institutions across the globe. The map outlines the distribution of these reciprocal research agreements, including the major institutions and universities that have a General Collaborative Agreement or Memorandum of Understanding with RIKEN.



Number of partner countries*



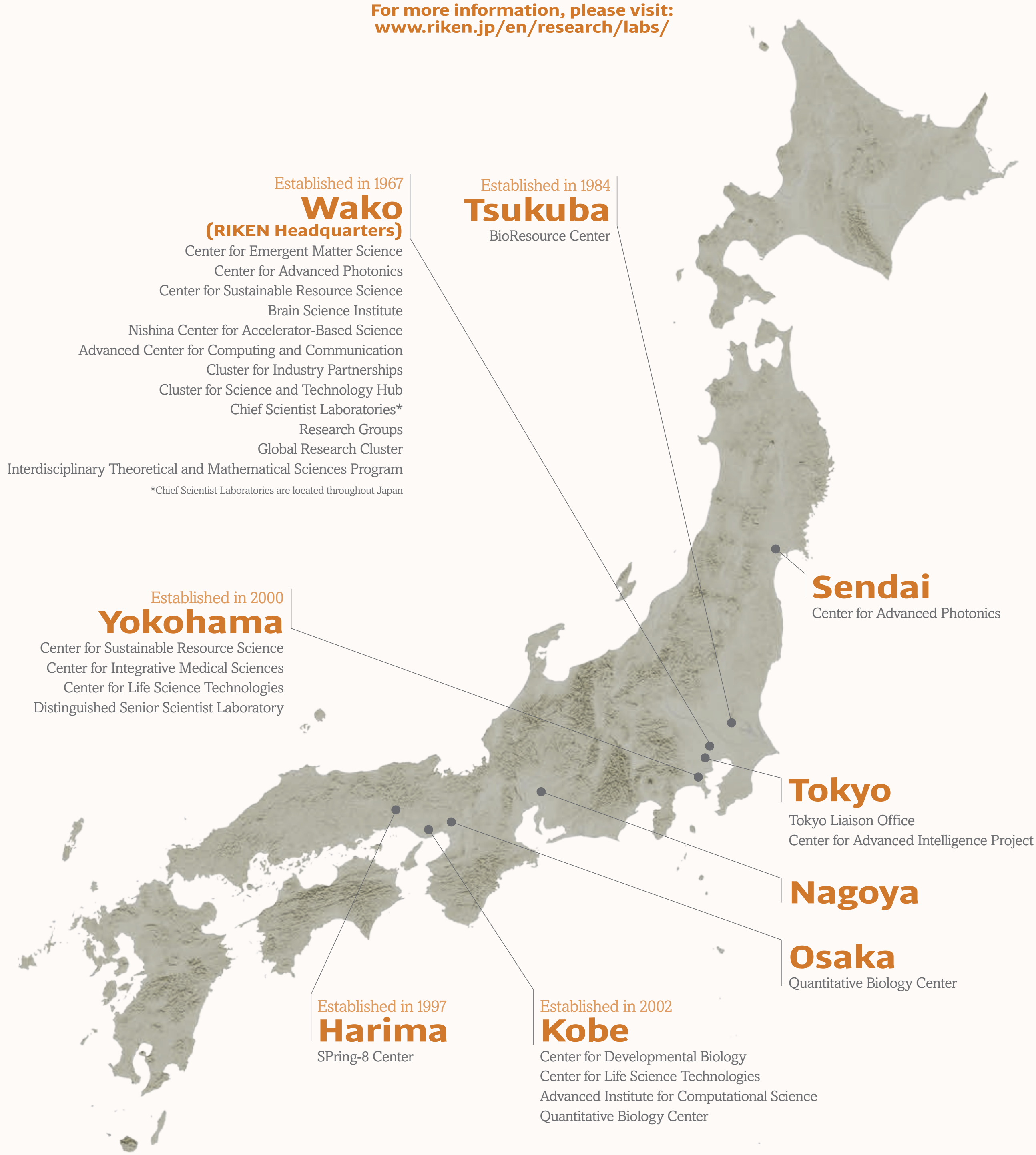
Number of collaboration agreements*



*As of 31 March 2016

Where is RIKEN?

For more information, please visit:
www.riken.jp/en/research/labs/



Since relocating its original campus from central Tokyo to Wako on the city's outskirts in 1967, RIKEN has rapidly expanded its domestic and international network. RIKEN now supports five main research campuses in Japan and has set up a number of research facilities overseas. In addition its facilities in the United States and the United Kingdom, RIKEN has joint research centers or laboratories in Germany, Russia, China, South Korea, India, and Malaysia. To expand our network, RIKEN works closely with researchers who have returned to their home countries or moved to another institute, with help from RIKEN's liaison offices in Singapore and Beijing.

For more information, please visit:
www.riken.jp/en/research/labs/
www.riken.jp/en/outreach/research/

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