# Preface

Pursuant to Article 8 of the Science and Technology Basic Law (Law No. 130 of 1995), this document reports the measures that have been conducted in order to promote science and technology.

In Part I and II of this document, various movements of science and technology activities will be described, and in Part III, the actual measures that have been conducted regarding the promotion of science and technology will be explained.

Part I, titled “Results of Promotion of Science and Technology - Creation, Utilization and Succession of Knowledge -,” examines the results of the promotion of science and technology from three points of view - creation of knowledge, utilization of knowledge and succession of knowledge - and provides explanations by citing specific cases. It also provides an outlook of how science and technology should be promoted in the future in light of the specific cases of people, research environment and public support involved. Part II provides an overview based on statistical data of science and technology-related activities in Japan and gives a comparison thereof with activities in other major countries.

# Introduction

The Third Science and Technology Basic Plan, started in fiscal 2006, calls for science and technology to be "supported by the public and to benefit society" as its primary tenet.

Based on the Science and Technology Basic Law, Japan has been promoting science and technology under three successive Science and Technology Basic Plans since fiscal 1996 and endeavored to expand government-funded R&D investments despite its tight fiscal condition.

Every edition of the Annual Report on the Promotion of Science and Technology describes in its Part 1 science and technology-related movements based on a specific theme, and this year's edition seeks to comprehensively introduce the results of the past efforts to promote science and technology to people. This reflects the beliefs that in order to obtain public support for the promotion of science and technology, it is essential to have people understand the results of the promotional activities, and that it is the responsibility of the government to endeavor to provide sufficient explanations in this regard if it is to promote science and technology.

In modern society, benefits of science and technology have spread throughout the whole society, supporting our lives as well as society. Many of these benefits have been reaped as a result of long years of research activities, and the process of moving technology from basic research to commercialization involves, in many cases, the interlocking web of the persistent large efforts of researchers and the research environment that supports the work and public financial support.

Meanwhile, research activities spurred by the intellectual curiosity or unfettered ideas of researchers may go on to create values that could be prized as intellectual assets for the whole of mankind, such as the discovery of new principles. Such achievement may have an impact on our concept of nature and mankind and on our thoughts, or serve as a seed of invention that will create significant social and economic values in the future.

Another important result of the promotion of science and technology is fostering of next-generation human resources. By engaging in research activities under the instruction of the teaching staff, young people who should play an active role in the future will obtain knowledge and acquire the ability for and habit of identifying problems for themselves and seek to resolve them through the process of trial and error. Human resources thus developed, including not only researchers and engineers but also other types of skilled people, play an active role in various sectors of society and support the foundation of society.

The achievements of R&D, inherited by next generation human resources, may lead to the discovery of new truths or create new economic and social values when applied to real-life society. Thus, there arises a cycle of knowledge created by human beings, inherited and utilized by other human beings, which in turn leads to yet another creation and utilization of new knowledge. All throughout this cycle, the capability of human beings involved is the critical factor.

The Third Science and Technology Basic Plan calls for a shift of emphasis from scientific infrastructures to human resources as its second tenet.

Part 1 of this report examines the results of the promotion of science and technology from three points of view - creation of knowledge, utilization of knowledge, and succession of knowledge - and provides explanations by citing specific cases. And then it provides an outlook of how science and technology should be promoted in the future in light of the specific cases of the people, research environment and public support involved.

# Chapter 1 Results of Promotion of Science and Technology

## Section 1 ■ Significance of Promotion of Science and Technology

### 1 Benefits produced by science and technology

#### (1) Science and technology in modern society

Today, as achievements in science and technology have spread throughout the whole society, our lives and economic activities owes much to achievements in science and technology. Therefore, modern states promote science and technology by establishing a variety of programs and mechanisms and by spending a vast amount of public funds under the commission of people. There is strong awareness that as a basis for promoting science and technology, it is necessary to have S&T understood by people and supported by society.

#### (2) Creation of intellectual and cultural values

Since the prehistoric era, mankind has explored outer space as well as oceans in an attempt to resolve questions about nature and "matter" and gone on to study the world of fundamental particles that constitute matter and the origin of the universe. Moreover, mankind has studied how life has come about in the first place and how the human species has evolved.

This activity of intellectual exploration aimed to resolve mysteries, rather than taking advantage of the knowledge acquired to develop practical technologies. However, it has created new knowledge and had great impact on people's concept of nature and mankind and thus transformed the behavior of individual people as well as the activity of society.

New knowledge, after being sorted out, systematized and passed on to new generations, constitutes part of mankind's common intellectual assets. Based thereon, we acquire further knowledge, and intellectual assets thus accumulated and inherited satisfy the intellectual curiosity of the subsequent generations of people and provide guidance on how to understand mankind, nature and society. Therefore, the richness of the culture of a society depends on to what degree the society has accumulated such intellectual assets.

Modern society is often called a knowledge-based society. It can be said that further development of Japanese society will depend on the level of accumulation of intellectual assets, and, therefore, the importance of scientific research will grow in the future.

While achievements in science and technology have made our daily lives convenient, science and technology have grown invisible to ordinary people. Alienation of ordinary people from science and technology could pose a threat to the very foundation of our society by undermining the breadth and diversity of our knowledge base.

In order to foster a social environment in which intellectual values are highly regarded and inquiring spirit is respected, it is important to implement measures for broadening and deepening people's understanding of science and technology.

### (3) Creation of economic and social values

The progress of science and technology has brought a variety of benefits to society and promoted economic development. Japan, in particular, achieved remarkable economic growth, supported by the technological progress due to vigorous research and development activities, among other things. Since then, there have been many cases in which the results of unique research by Japanese researchers eventually led to the development of new products and produced economic effects.

For Japan, which has limited natural resources, its technological prowess backed by science achievements acts as the engine of economic development and serves as the source of its national power amid intensifying competition with other countries.

Besides, improvements in medical treatments and food supply conditions due to the progress in science and technology have remarkably extended life expectancy and helped to overcome many diseases. Moreover, forecasts of natural disasters and disaster prevention and mitigation technologies have made our lives safer, and advanced traffic systems have made it much more convenient. In addition, the progress in information and communications technologies in recent years has made great contributions to the creation of new means of entertainment.

### (4) Positive and negative aspects of science and technology

Although science and technology have generated a lot of benefits for us, an expansion of human activity due to the rapid progress in science and technology caused depletion of resources and environmental problems such as global warming and the destruction of the ozone layer, and also widened the economic gap between developed and developing countries. Moreover, there have arisen ethical problems related to the fundamentals of life due to genetic engineering, for example.

If we are to enjoy the benefits of the progress in science and technology, we should naturally deal with the problems brought about by it as well. In this context, it will become more important to make efforts to forge a consensus, based on open debate, as to how a certain technology should be utilized and how its impact should be controlled.

Global environmental problems and many other worldwide problems have arisen due in part to the rapid progress in science and technology. However, appropriate utilization of science and technology is essential for resolving those problems, and we pin high hopes on the future role that science and technology will play in efforts to resolve such problems.

## 2 Science and Technology Basic Plans and government R&D investment

Since the Meiji Era, science and technology have acted as the engine of the modernization of Japan, the country’s postwar reconstruction and the ensuing high economic growth. In recent years, Japan has been promoting science and technology through public-private joint efforts, with a view to becoming an advanced science and technology-oriented nation.

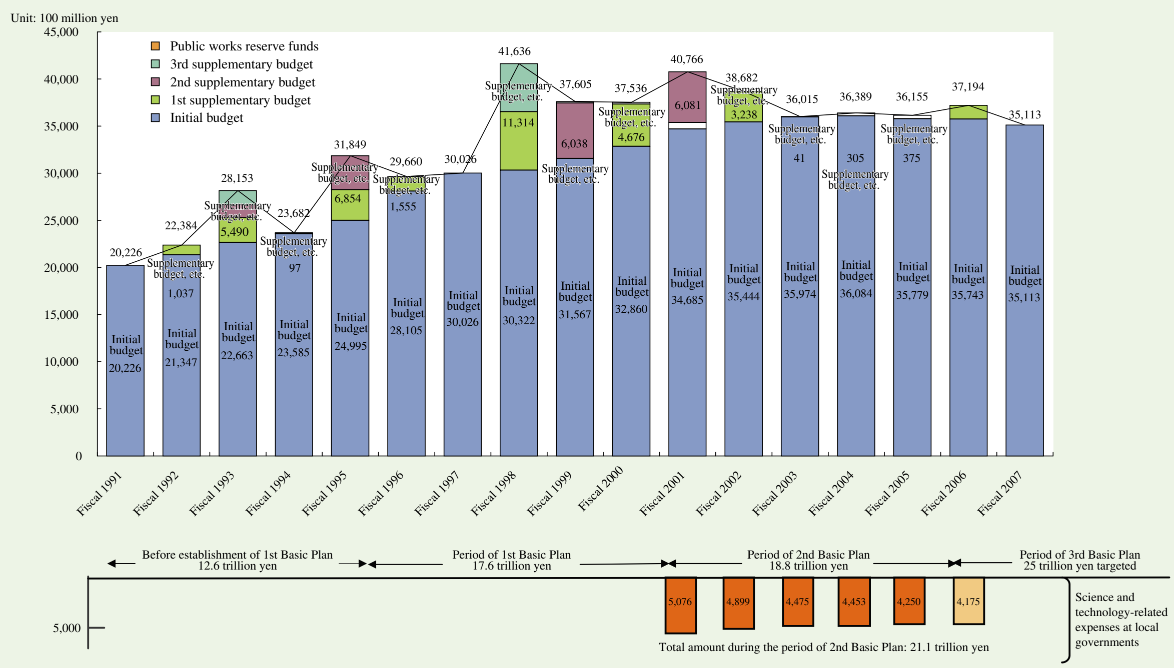
Since the Science and Technology Basic Law was established in 1995, the Government as a whole has implemented measures for promoting science and technology under three successive Science and Technology Basic Plans (the first for 1996-2000, the second for 2001-2005 and the third for 2006-2010).

Investments under the First and Second Science and Technology Basic Plans totaled 38.7 trillion yen (Figure 1).

Under the Third Science and Technology Basic Plan, it is necessary to keep the amount of governmental R&D investments as a proportion of GDP at a level similar to the ones in the United States and European countries. To do so, investments totaling 25 trillion yen are expected during the period covered by the third plan (This figure is based on the assumption that governmental R&D investments during the period of the third plan in GDP will be 1% of GDP and that annual GDP growth will average 3.1% during the period in nominal terms).

The Third Science and Technology Basic Plan calls for “science and technology to be supported by the public and to benefit society” as its primary basic tenet in implementing the plan. Thus, the plan stipulates that it is necessary to obtain public understanding of and support for science and technology through measures such as increasing efforts to feed back the results of R&D to society and people and providing comprehensive explanations concerning science and technology policies and their results.

## ■ Figure 1 Trends in science and technology-related expenses




The amounts in fiscal 2001 and thereafter include science and technology-related expenses at local governments (The figure for fiscal 2006 represents the initial budget).

## 3 Results of promotion of science and technology

In many cases, the fruits of science and technology can be reaped only after many years of dedicated efforts, and it is not unusual that the origin of technologies now available and products now widely used dates back to 20 or 30 years ago (Table 2).

### ■ Table 2 Time of invention/discovery to commercialization regarding technology seeds

| Technology | Time to commercialization | 1960 1970 1980 1990 2000 2010 2020 2030 | Outline of invention/discovery |
|---|---|---|---|
| Helical CT tech. useful for early detection of lung cancer | Approx. 10 years | | 1982: Acquisition of helcal CT patent by a private company (Japan)<br>1991: commercialization of helcal CT (Japan) |
| Perpendicular magnetic recording tech. (for HDD) | Approx. 30 years | | 1976: Invention of perpendicular magnetic recording tech. by a university (Japan)<br>2005: commercialization of HDDs using perpendicular magnetic recording tech. (Japan) |
| Tech. to increase density and extend operating life of lithium batteries | Approx. 10 years | | 1979: Development of lithium cobalt oxide as positive electrode material (UK)<br>1991: commercialization of lithium batteries using lithium cobalt oxide in positive electrodes (Japan) |
| Photocatalyst materials | Approx. 30 years | | 1967: Discovery of photo disintegration of water (Japan)<br>1994: commercialization of tiles/building materials using photo catalyst (Japan) |
| Residential photovoltaic power generation system | Approx. 40 years | | 1954: Fabrication of solar cells by Bell Laboratory (US)<br>1994: Start of subsidy program for Residential photovoltaic power generation systems (Japan) |
| Laser-based processing tech. | Approx. 20 years | | 1960: Dr. Maiman's successful attempt to produce laser beams using ruby laser (US)<br>1980s: Wide applications of laser for processing (Japan) |

: Period between innovation/discovery and commercialization regarding technology seeds

Source: "Study for Evaluating the Achievements of the S&T Basic Plans in Japan" by the National Institute of Science and Technology Policy (NISTEP Report No.89, March 2005)

# Section 2 ■ Creation of Intellectual Assets of Mankind - Creation of Knowledge -

## 1 Results of the creation of knowledge

The dramatic advancement of basic science in the 20th century gave rise to completely new technologies, which in turn advanced science further. As a result, things that the original researchers did not even imagine have become realities. Through this remarkable advancement of science and technology, mankind has learned much about nature, and his awareness of it has changed drastically.

## 2 Exploring mysteries of space and matter

Mankind's interest in and intellectual curiosity about the paths of the sun, the moon, and stars have caused mankind to shift from the geocentric view to the heliocentric view, completely revolutionizing their worldview and the way they view nature. The knowledge of astronomy has made significant contribution in establishing fundamental laws of physics such as Newtonian mechanics and the general theory of relativity.

Atoms became a subject of experiments and observation in the 20th century. Particle physics, supported by revolutionizing theories such as quantum theory and relativity theory, made tremendous progress. Particle physics continues to grow in pursuit of the ultimate theory and is changing into a discipline that addresses deep and enormous problems such as why the universe exists in the form it does. Japanese scientists have been making original contributions that lead the world in these fields.

### (1) Pioneers of particle physics

Dr. Hideki Yukawa, the first Japanese Nobel Prize laureate, submitted a paper in 1935, predicting that protons and neutrons are connected by a force (nuclear force) generated by exchange of mesons[1]. This theory is a result of Prof. Yukawa's high ambitions and his endurance in hard work since his days as a student. Also behind his success were discussions with superior young researchers like Dr. Sin-itiro Tomonaga and the new, liberal research environment, provided by a pioneer of Japan's electronic engineering, Dr. Hidetsugu Yagi, who tore down the wall of the "*Koza* (chair) system" for Dr. Yukawa[2]. Dr. Yukawa's prediction on mesons led to the discoveries of many other elementary particles, ushering a new era of the theory of elementary particles.

Around 1940, there were major problems in "quantum field theory[3]," which describes elementary particles: there was a problem with its relation to the theory of relativity, and the calculations suggested that the mass of an electron might become infinite. Dr. Tomonaga resolved these problems by publishing "super-many-time theory" in 1943 and "renormalization theory" in 1947. Today, quantum field theory and the renormalization theory provide the foundations of a

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[1] Meson: Dr. Yukawa predicted that a particle that mediates the force connecting protons with electrically neutral neutrons has a mass about 200 times the mass of an electron. Today, the mesons predicted by Dr. Yukawa are called pi-mesons.

[2] *Koza* (chair) system: Under the university setup standard, this system first determines the major fields of study required for education and research and then places teaching staffs required for the education and research.

[3] Quantum field theory: theoretical framework that can integrate generation, decay, and other phenomena of particles including photons (electromagnetic waves), electrons, protons, and all other particles; this theory was born as an extension of quantum mechanics.

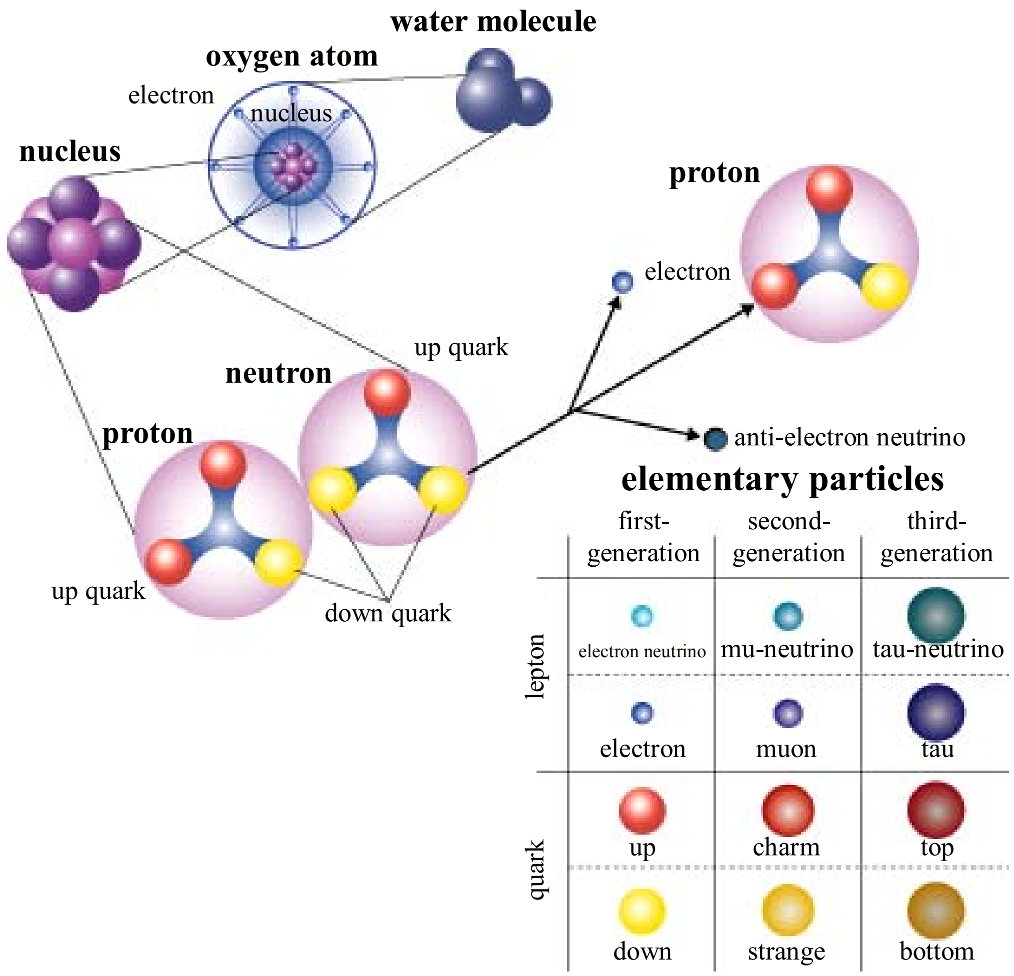
theoretical framework not only in particle physics and nuclear physics but also in condensed matter physics, dealing with properties unique to various substances such as semiconductors and super conductors, forming one of the most critical pillars of modern physics.

In 1955, Dr. Shoichi Sakata proposed what is known as the “Sakata model,” which was to become the prototype for the quark model[4] today. In 1962, together with Drs. Jiro Maki and Masami Nakagawa, he made the hypothesis that neutrinos, a type of elementary particle whose mass had been assumed zero, might have a mass, and proposed the theory of “neutrino vibration,” suggesting that a neutrino could change to a different type of neutrino.

When the universe was created, “particles” and “antiparticles,” having opposite properties, must have existed in the same quantity. However, today the world consists only of the “particles.” This implies that the particles, at some time, became more numerous than the antiparticles; this is called the problem of “violation of CP symmetry[5].” In 1973, two researchers who had been in the Sakata Research Group, Dr. Makoto Kobayashi and Dr. Toshihide Maskawa, published a paper explaining this violation of CP symmetry. In doing so, they predicted that, while there were only three types of quarks known at that time, in fact at least six types of quarks must exist. Later, indeed six types of quarks were discovered (Figure 3). This “Kobayashi-Maskawa theory” has now become a critical element of the “standard theory[6],” which is at the foundation of today’s particle physics and continues to have significant impact.

[4] Quark: elementary particle that forms protons and neutrons, each of which consists of three quarks of two types.
[5] CP symmetry violation: The “C” stands for the conjugation of the electric charge or a unique value that the particle has, and the “P” represents the parity of the space axis. If both C and P are switched (CP transformation), i.e., replacing the elementary particle with its anti-particle and performing a mirror-image transformation, most of the time the physical laws remain unchanged—this is called CP symmetry. However, it was discovered that, by rare breakdown of K mesons, CP symmetry is slightly violated.
[6] Standard theory: Currently known forces include the “weak force,” which triggers breakdown of mesons, “electromagnetic force,” “strong force” such as nuclear power, and “gravity.” The standard theory is the combination of three theories: quantum chromodynamics, which explains the strong force, a theory that explains electromagnetic force and weak force in an integrated way, and the Kobayashi-Maskawa theory.

■ **Figure 3 Hierarchy of matter and elementary particles**




Source: Prepared by the Ministry of Education, Culture, Sports, Science and Technology, based on sources of the University of Tokyo

The High Energy Accelerator Research Organization (KEK) built a B factory accelerator (KEKB) which can create B mesons and anti-B mesons to conduct experiments to measure the size of the violation of CP symmetry, proving the "Kobayashi-Maskawa theory."

The remarkable contribution made by Japanese researchers in the physics of elementary particles provides vivid examples of the trend that theoretical physicists learn and carry on the insights of their predecessors and then boldly propose innovative theories that exceed those, which are then validated by experimental physicists so that the theorists and experimenters form a pair to advance the creation of knowledge.

### (2) Further development of particle physics and its integration with cosmology

Dr. Chushiro Hayashi, who used to be an assistant at the Yukawa Research Group, published a theory in 1950 concerning the origin of the elements in the universe in the early stages of the Big Bang. He then went on to publish a process of evolution from the birth to the death of a star as well as a model in which the origin of the solar system is theoretically analyzed. More recently, due to the remarkable progress made in radio waves, optical/IR telescopes, and detectors, it has become possible to measure the domain of planet formation outside the solar system. Many of the facts discovered through such measuring provide new evidence that the model constructed by Dr. Hayashi should be correct.

In 1983, Dr. Masatoshi Koshiba completed "Kamiokande" to search for a phenomenon known as proton decay[7] and modified it later so that it can detect neutrinos coming from the sun and supernovas. Consequently, in February 1987, he became the first person in the world to detect neutrinos generated by an explosion of a supernova that occurred in the Large Magellanic Cloud. This showed that the theory of supernova explosions is very likely correct, giving rise to neutrino astronomy, in which neutrinos are the means of measurement.

The Kamiokande was further expanded to the Super Kamiokande, established by Dr. Yoji Totsuka and others who were taught by Dr. Koshiba. In 1998 they published that they had confirmed a phenomenon called "neutrino vibration," in which generated neutrinos change to another type of neutrinos in flight. This phenomenon implies that neutrinos have a mass and that there is a need for a grand unified theory[8] that goes beyond the standard theory. Neutrino vibration was further confirmed by a series of experiments conducted from 1999 to 2004 in which, for the first time ever in the world, an artificial neutrino beam generated by a proton synchrotron of the KEK was caught in Kamioka, 250 km away.

Dr. Atsuto Suzuki and others, who had been involved in the construction of the Kamiokande, built "KamLAND," with which super-low energy neutrinos can be identified, and they detected, in 2005, antineutrinos (earth antineutrinos) generated by the decay of uranium and thorium in the interior of the earth. The fact that the earth's antineutrinos, which directly contribute to producing heat in the earth's interior, can now be observed implies that we now have a new method for

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[7] Proton decay: While the standard theory states that protons last indefinitely, the grand unified theory predicts that they decay over a very long period of time; this is referred to as proton decay. As of now, this decay has not yet been confirmed.

[8] Grand unified theory: an attempt to integrate weak force, electromagnetic force, and strong force into one. This theory predicts phenomena like proton decay and neutrino vibration. The smallest model of this theory was proved wrong by measurement results of the life of protons through the Super Kamiokande and other experiments.

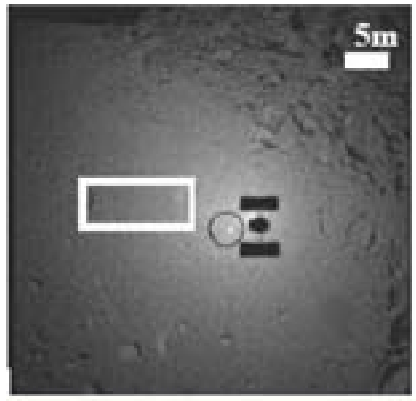
research of the earth's interior, which has conventionally been done using seismic wave analysis, etc. A new research field called "neutrino geophysics" was thus born.

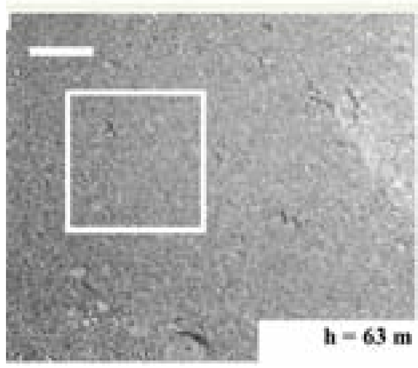
When we see stars, the light emitted from those stars long ago is reaching us over a long period of time. By observing the appearances of heavenly bodies farther and farther away, we can understand what the universe was like in its early stages.

"Subaru," operated by the National Astronomical Observatory of Japan (NAOJ), National Institutes of Natural Sciences, is a large-scale optical-infrared telescope with a diameter of 8.2 m, largest in the world for a single mirror, and the galaxies observed by "Subaru" are considered as some of the farthest galaxies whose distances have been accurately measured. These galaxies are young galaxies, born about 900 million years after the birth of the universe.

On planets such as the earth and Mars, diastrophism, weathering and erosion by the atmosphere and water have left us with no surface evidence from the time of birth. On the other hand, it is thought that small bodies such as asteroids are like time capsules, retaining the conditions when the solar system was born. From September to November 2005, "Hayabusa," an engineering experimental explorer, equipped with a variety of revolutionary technologies including a highly efficient engine necessary for planet exploration, autonomous navigation, sample gathering, and sample collection by re-entry capsule from an inter-planetary orbit, made a rendezvous with the asteroid Itokawa, which is so far away that it takes a radio wave from the earth 17 minutes one way to reach it. Various scientific observations were made, and "Hayabusa" succeeded in landing and taking off from Itokawa. The observation made by "Hayabusa" has shown that the asteroid Itokawa is highly likely to be a "clump of debris." It has discovered, for the first time in history, a theoretically conceived celestial body that is in an intermediate stage of the formation process of a planet, revealing in detail the image of a very small asteroid drawing near to the earth (Figure 4).

■ **Figure 4 Asteroid explorer "Hayabusa"**


Top left (i): Explorer "Hayabusa" before launch
Top middle (ii): Cover of the special issue on "Hayabusa" of the scientific journal Science
From Science Vol. 312, No 5778, 2 June 2006.
Reprinted with permission from AAAS.

Top right (iii): Unprecedented landing and take-off from the surface of an asteroid
Bottom (iv): Most detailed image ever of the surface of an asteroid (the white scale represents 1 meter)

(i), (iii), (iv): Photos provided by the Japan Aerospace Exploration Agency
(iii), (iv) Photos by H. Yano, et al., Science (2006)

Generation of all substances in the universe involves nuclear reactions, but we do not yet know much about the reactions of about 10,000 kinds of unstable nuclei called radioactive isotopes (RIs). At the Institute of Physical and Chemical Research (RIKEN), Dr. Isao Tanihata, et. al. invented a technique for producing and using RI beams in the mid-1980s and discovered a phenomenon called neutron halo[9], which cannot be explained using the standard nuclear model. Triggered by this discovery, the exploration of the world of atomic nuclei by RI beam experiments[10] has begun. At RIKEN, researchers are pursuing their hope of understanding the process of element synthesis in space and pioneering a wide range of application research in physical properties, materials, chemistry, and living organisms.

## (3) Results derived from quantum mechanics and particle physics

Derived from high energy physics, synchrotron radiation[11] is used in nano-size fabrication of

[9] Neutron halo: condition in which excess neutrons are spread thin around the atomic nucleus, a core, with an extremely large radius. In stable nuclei, protons and neutrons exist together in a mixed state, and the volume taken by protons is about the same as the volume taken by neutrons (common knowledge in conventional nuclear physics). However, in recent experiments using RI beams, when one examines the structures of the unstable nuclei of light elements with excessive neutrons (e.g., $^{8}$He and $^{11}$Li) in detail, it was found that neutrons are distributed to those located in the normal core part and those excess neutrons that spread afar.
[10] RI beam experimentation: method of producing high-speed particles of unstable nuclei (radioactive isotopes: RI) and using them to cause diffusion or reactions in order to study the properties of the RIs.
[11] Synchrotron radiation: When the motion of electrically charged particles (electrons and protons) moving at speeds near the speed of light is bent by a magnetic field, electromagnetic waves are emitted in the direction of motion. This is synchrotron radiation and has many superior properties such as being extremely bright and highly directional, and the polarization characteristic of the light can be freely changed. Initially this was considered merely a loss of energy resulting from accelerators used in particle experiments.

semiconductors, non-destructive inspection, analysis of the structure of protein, and ultramicro analysis. The medical field uses diagnosis by positron emission tomography (PET), which uses positron emission nuclides as tracers, image diagnosis of coronary arteries via synchrotron radiation, photon therapy to target and shoot cancer cells, and heavy-particle radiotherapy using carbon ions. Another example close to home is cathode-ray tubes in television sets, which use the principle of an accelerator.

Quantum mechanics has become a foundation for the development of various fields such as IT, laser technology, magnetic resonance imaging (MRI)[12], and nanotechnology. As an example of applying a concept of quantum mechanics in the field of electronic engineering, Dr. Leo Esaki validated the quantum tunnel effect[13] with solids in 1957 and invented a tunnel diode. Since then, the tunnel effect has been applied in a variety of fields such as flash memory and scanner-type tunnel microscopes. In 1952, Dr. Kenichi Fukui applied quantum mechanics in the theory of chemical reactions and published "Frontier Orbital Theory[14]," which reversed the conventional organic electronics theory.

The idea of quantum mechanics will likely gain acceptance among the people in the future and will likely make further contribution to our life. For example, the performance improvement of computers by size reduction of CPUs is believed to have limitations; however, basic research is being carried out to explore the possibility of creating a completely new type of information system by controlling quantum behaviors.

Column 1: "Joy of quantum computer research, where new paths are opened up by changing the frame of mind" (Dr. Kae Nemoto, associate professor of the National Institute of Informatics, Research Organization of Information and Systems)

## 3 Challenging the mysteries of the earth and the oceans

Oceans and the deep parts of the earth are frontiers of mystery, even today. In particular, the oceans and crust surrounding Japan form a very complicated environment, and it is thought that many unknown organisms exist there.

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has been using "Shinkai 6500," with the capability to submerge deeper than any other manned exploratory vessels in the world and "Kaiko," an unmanned exploratory vessel that can reach the deepest trench in the world for exploration, making contribution to the research on topics including deep-sea earthquakes, earth's activities, and life in the deep sea. One of the recent results is the discovery, made during a study in 2003 and 2004 in the region of hydrothermal activity in Okinawa, of a special environment called a liquid carbon dioxide pool, revealing, for the first time in the world,

[12] Magnetic Resonance Imaging, MRI : method of using the nuclear magnetic resonance phenomenon to create an image based on information inside a living organism.
[13] Quantum tunnel effect: phenomenon wherein quantum effects enable very small particles to be filtered through a potential (energy) wall, which they cannot go through by the classical theory.
[14] Frontier orbital theory: the theory that the main process of chemical reactions is the mutual action between the molecular orbit in one molecule where the electrons with highest energy are distributed (highest occupied molecular orbital) and the molecular orbit of the other molecule with the lowest energy where no electrons exist (lowest unoccupied molecular orbital). This theory has contributed significantly to the understanding of reaction mechanism in organic chemistry and has been used in the new field of molecular synthesis.

that there exist microbes whose nutrient source is carbon dioxide.

In addition, in another sea region of Okinawa, a blue hydrothermal spurt (blue smoker) was discovered, also for the first time in the world, erupting out of a hydrothermal spout in August 2006. Hydrothermal vents are thought to be an environment very similar to that of the ancient Earth. Many thermophilic bacteria have been found in hydrothermal vents. Further studies of these thermophilic bacteria may solve mysteries involved in the origin of life.

**Discoveries at deep oceans**

Left: Blue smoker is erupting out (red arrow). White smoker is also erupting on the left (yellow arrow).
Middle: Spiral shell with scales of nano-crystal iron sulfide that appears like armor.
Right: Super-thermophilic bacteria of a new species and a new genus, isolated from a 365℃ hot-water chimney on the deep ocean floor

Photos provided by the Japan Agency for Marine-Earth Science and Technology

Super-thermophilic bacteria-based enzymes are used in biological research and DNA amplification reaction, which is indispensable to DNA testing. They are also believed to play a crucial role in studies of protein denaturation, which causes various illnesses such as Alzheimer's disease and Prion brain disease.

"Urashima," a deep-sea exploring cruiser in operation, is an automatic unmanned vessel capable of carrying out sample-water analysis and ocean floor analysis. It is producing results through hydrographic sounding, like capturing the detailed structure of the surface of mud volcanoes on deep ocean floors.

There have been accomplishments on the interior of the Earth as well, such as the discovery of a group of microbes inside the Earth's crust and an explanation of the mechanisms of the formation of continental crust and of the occurrence of earthquakes.

Meanwhile, through advancement in various measuring methods and analysis using the methods of molecular biology, Japanese researchers have gained some crucial knowledge concerning the behaviors of organisms close to us. For instance, in June 2005, Dr. Katsumi Tsukamoto, et. al. of the University of Tokyo discovered that Japanese eels (Anguilla japonica) lay eggs on the day of the summer new moon at Ocean Mountain Suruga seamount off the coast of the Mariana Islands.

Through this success it is hoped that more analysis will be carried out to determine the evolutionary reason for fish migration and the mechanism by which the migrating fish sense the earth's magnetic field. Further, it is expected that gaining understanding of the reproductive behaviors of eels in nature will lead to useful knowledge for farming eels, a resource whose depletion is feared.

With regard to Antarctic observation, the Deep Ice Coring Project at Dome Fuji, a 3-year plan, was started in 2003. Digging began to reach the rock plate estimated to exist 3,030 meters below the ice sheet. In January, 2006, a team led by the 47th Antarctic region observation team succeeded in collecting an ice sheet core (ice sample) down to a depth of 3,028.52m. The analysis of the ice sheet core has shown that the deepest part of the sample represents ice from about 720,000 years ago, which makes it the second oldest ice sheet core in the world. Further digging carried out by the 48th Antarctic region observation team led to successful collection of rock particles of a few mm, considered to have come from an ice sheet core or a rock bed down to a depth of 3,035.22m on January 26, 2007.

Because ice sheet cores (ice samples) contain enclosed substances and air in their air bubbles, analyses of the ice sheet cores can lead us to the understanding of past global environmental and climate changes. Currently, various analyses and studies in relation to climate prediction are being carried out jointly by universities and the National Institute of Polar Research under the Research Organization of Information and Systems.

## 4 Exploration of life

About 30 million years ago, the family hominidae[15] of organisms diverged from monkeys, and about 5 million years ago, chimpanzees and humans split, and from the branch of humans came Homo sapiens about 200,000 to 300,000 years ago.

The search for answers to the question of what these living creatures called humans are is under way currently through a variety of scientific approaches, such as through research on genes, on the immune system, on the brain, and on primates, in which humans are compared with other primates besides humans to find out what humans are.

### (1) Genome analysis

In 2003, the "International Human Genome Project," which had begun in 1991 through international cooperation of the U.S., U.K., Japan, France, and Germany, completed the decoding of all of the base sequences of the human genome, the basic human blueprint. Japan participated in this project chiefly through the Genomic Sciences Center of RIKEN, led by Dr. Yoshiyuki Sakaki. The team played a central role in the analysis of chromosomes Nos. 21 and 11, making a 6% contribution in the total project, which is the third highest percentage following the U.S. and the U.K. Further, the team played other major roles in that it contributed to the development of high-performance human genome analysis equipment such as an automatic DNA sequencer to decode the genes.

Now, the research in this field is said to have entered the next stage—the post-genome era. Supported by current results of decoding all base sequences, this new research studies the functions of the genes, various proteins formed from the genes, the formative process of our complicated human bodies, development of new medicines, and "tailored medication[16]," in which individual

[15] The family hominidae is one family under the order primates under the class mammalia. The family includes, in addition to humans (Homo sapiens), chimpanzees, gorillas, and orangutans.
[16] Medical treatment in which gene information is used to select the most effective treatment or medicine with the least side effects for each individual patient.

differences in the base sequence are applied to medical treatment and many other issues.

The 3 billion base sequences of the human genome vary from person to person by 0.1%, causing different appearances, body shapes, and physical properties of individuals. HapMaps, which are the maps of these differences in base sequences, provide crucial basic information to determine the likelihood of diseases and the effectiveness of medicines and to discover the gene factors contributing to side effects, etc., so they are indispensable to the implementation of tailored medication, etc. The “International HapMap Project” was a project whose purpose was the creation of a database of HapMaps. It began in 2002 under international collaboration and was completed in 2005. From Japan, the RIKEN SNP Research Center, led by Dr. Yusuke Nakamura, participated in the project, contributing 24.3% (following the U.S.’s contribution of 32.4%). It was the largest contribution among the participating research organizations.

In addition, post-genome research has made the important discovery that hereditary information is not determined by genes alone but many other factors besides the genes contribute to it. For example, we now know that some domains besides those containing genes are actually crucial domains containing information such as RNAi (RNA interference), which controls the manifestation of DNA information. Additionally, it has been discovered that the formation of proteins from the gene information depends in part on the information-control mechanism (epi-genetics), different from the genes, contained in proteins and chemical substances surrounding the DNA.

### (2) Immunology

The research field of immunology has become a fundamental research area common to cutting-edge medical treatment involving medical transplantation and cancer treatment and challenges such as new and recurring infections including allergies (like pollen allergies), atopic dermatitis, and AIDS.

Dr. Shizuo Akira of Osaka University found receptors called TLRs (toll-like receptors) and discovered that cells originally have these receptors that can sense the invasion of pathogens and that, when such a pathogen enters the body, these receptors are activated by the constituting elements of the pathogen, inducing subsequent inflammation and immune reactions. Further, he discovered that the action of acquired immunity gets induced only by the recognition of pathogens by the TLRs. These discoveries are significantly changing the way people think about vaccines against infectious diseases, allergies, and immunity against cancer. Currently, research is being done to study the mechanisms of activation of the natural immune system from TLRs’ recognition of disease-causing pathogens and of activation of the acquired immune system from the natural immune system.

Dr. Hiroshi Takayanagi of Tokyo Medical and Dental University discovered that T cells[17] of the immune system not only produce molecules that promote the formation of osteoclasts but also produce, significantly, the molecules that inhibit the operation of these promoter molecules; his discovery shows that autoimmune arthritis is a disease caused when the balance of these molecules

[17] T-cell is one of the immunity cells, controlling the reaction of acquired immunity and attacking foreign objects that have entered the body.

is broken and a large number of osteoclasts are produced, proving that molecules in the immune system contribute to bone metabolism. These discoveries have given rise to a new research field called "Osteoimmunology."

### (3) Brain science

Through progress of research in brain science and by accumulating various knowledge concerning the brain, it is expected that we can obtain fundamental solutions to brain aging as well as mental and neurological illnesses; applications to engineering such as the development of computers via information-processing methods emulating the brain function; and solutions to the problem of the relation between the brain and the heart.

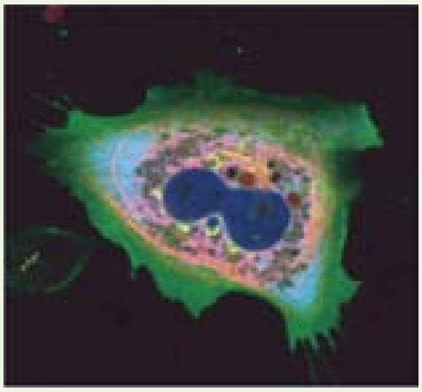
In recent years, research in brain science is advancing in a variety of fields, taking advantage of cutting-edge technology such as molecular biology, research results from hereditary studies, MRI (Magnetic Resonance Imaging), and PET (Positron Emission Tomography).

At the RIKEN Brain Science Institute, research is being carried out with the four investigative target areas: "understanding the brain," "protecting the brain," "creating the brain," and "nurturing the brain." In particular, many research results related to mental and neurological illnesses are being reported, including the discoveries of the genetic abnormality associated with autism and of the group of genes associated with the outbreak of schizophrenia, understanding of the mechanism of neurological growth to repair damaged nerves, and understanding of the mechanism of decomposition of substances causing Alzheimer's disease.

Dr. Yasushi Miyashita of the University of Tokyo has clarified the memory mechanism of the cerebrum, answering questions such as "Where is the memory stored?" "How is the memory built?" and "How is the memory recalled?" He discovered a neurological cell group in the cerebral temporal lobe that is used to memorize shapes. He also discovered that the memory nerve cells solidify the memory not only by information from the cerebral sensory area but also by signals from the part called the hippocampus of the brain. In addition, he discovered that the basic mechanism of recalling what is memorized is not by physical signal of sensory organs but by the neurological cell group in the cerebral temporal lobe getting activated by signals from the interior of the brain. He also went on to find a signal that originates these in-brain signals. It is expected that these discoveries will contribute to further understanding of the causes of dementia, amnesia, etc. and to the development of how to treat these diseases.

Dr. Atsushi Miyawaki of the RIKEN Brain Science Institute is developing various fluorescent proteins, indispensable to imaging of living cells. In the field of biology, there are various phenomena that cannot be decisively answered without observing what is happening in living cells; these new fluorescent proteins have enabled us to visualize, spatially and chronologically, the various phenomena occurring in individual cells like neurological cells, real-time. This has now become a tool indispensable in research laboratories around the world (Figure 5).

**■ Figure 5 Imaging of cells with fluorescent proteins**



Multi-color imaging using 6 colors
Cell membrane: green
Small cell: light blue
Golgi body: yellow
Microtube: red
Nucleus: dark blue
Mitochondrion: pink

Photo provided by Dr. Atsushi Miyawaki

## (4) Primate studies

What is the difference between mankind and other animals? What are the origins of mankind and their society? To answer these questions, it is natural to study other primates besides human beings, such as chimpanzees.

While much of the basic research originated in Western Europe, studies of primates originated in Japan, and it is one important area of research where Japan is leading. Drs. Kinji Imanishi and Junichiro Itani of Kyoto University began studying the social structure of Japanese monkeys for the purpose of discovering the origin of human society in the society of wild animals, back in 1948. They successfully found that Japanese monkeys have social structures like people, as evidenced by their hierarchical social relations. In 1958, they extended their research scope to chimpanzees and gorillas living in Africa to study anthropoids and discovered that they too have social structures. In 1953, they made a new discovery that Japanese monkeys adopt pre-cultural behavior such as washing sweet potatoes and explained mechanisms like propagating their behavior to the entire group and passing them down to next generations.

One remarkable work in recent years is the results from the “Ai Project” by Dr. Tetsuro Matsuzawa of Kyoto University. This project seeks to show, both experimentally and objectively, how chimpanzees recognize this world as well as their intelligence and thoughts; it is a project of “comparative cognitive science” which seeks to clarify the evolutionary origin of recognition and thoughts of humans. Research up to the present has shown the high level of intelligence of chimpanzees, in that the color recognition ability in chimpanzees is basically the same as that in humans and that chimpanzees’ immediate memory capacity is about as high as the capacity of a normal human adult (Figure 6). In their habitats in Africa, some wild chimpanzees have been observed using a variety of things such as stone tools, and it has been discovered that such knowledge and techniques have been carried down over the generations as cultural traditions and that each group has different culture of its own. At present, research is being conducted to simulate the beginning and propagation of wild chimpanzee culture by studying how the knowledge obtained at a research center is propagated over generations or throughout a group. Research is also under way to study the recognition development of child chimpanzees.

■ **Figure 6 Chimpanzees at the Primate Research Institute, Kyoto University**

Top left: Outdoor playground at the Primate Research Institute. The physical environment is made similar to the environment which wild chimpanzees inhabit to provide a natural place for the chimpanzees.
Top right: Ai's son Ayumu, taking a "test of numeric memory span"
Bottom right: Ai, facing Prof. Matsuzawa in the lab, and Ayumu, held by the professor

Photos provided by the Primate Research Institute, Kyoto University

## 5 Exploring the mysteries in history

A regional study by Japanese scholars is showing unique advances particularly in the region of Southeast Asia. Since 1991, a Sophia University international study group on Angkor ruins (group leader: Yoshiaki Ishizawa, president of Sophia University) has been carrying out preservation and repair work as well as archeological excavation at the Banteaysrey ruins inside the Angkor ruins. While making this study, the team came upon 274 Buddha statues and the “Thousand Buddhas Over a Quadrilateral Pillar” (“Mille bouddhas sur un pilier quadrangulaire”) in 2001.

In the 140-year history of studies and research of the Angkor ruins, which began in late 19th century, this is the first time so many Buddha statues were uncovered.

Most of the excavated statues of Buddha had been cut asunder into heads and bodies before they were buried. This was done because the new Hindu king, who fought battles against Buddhist powers to win his kingship, had these statues (which the earlier kings worshipped) destroyed and buried to teach a lesson. This discovery suggests that it was an era when the authority of the new king was sufficiently established and the government functioned normally. It thus overturned the traditional view that the Angkor dynasty had “deteriorated and degenerated” and proved that the dynasty actually “kept a certain level of prosperity,” rewriting the history of the latter part of the Angkor dynasty.

Since its entry in Cambodia in 1982, the international study group on Angkor’s ruins from Sophia University has been actively involved in training personnel, Cambodian officers to preserve the ruins, through various means such as workshops on archeology and architecture, along with their work on excavation and protection of Angkor's ruins.

Column 2: "Most famous Japanese person on wall street" (story about Dr. Kiyoshi Ito, professor emeritus of Kyoto University, who received the Gauss Prize)

# Section 3 ■ Returning the Results of Science and Technology to the Society - Utilization of Knowledge –

## 1 Results of science and technology that have changed the society

### (1) Maintaining health and overcoming diseases

Advancement in science and technology has improved the standards of medical practice, nutrition, and hygiene conditions. On the other hand, however, health maintenance is now facing new challenges such as how to deal with various metabolism-related syndromes (obesity, diabetes, hyperlipidemia, high blood pressure, hyperuricemia, etc.) as well as cancer. Rapid internationalization is also making it necessary for us to prepare for unknown infectious diseases.

Here, we give examples of "utilization of knowledge" involved in the development of therapeutic technology and medicinal products.

#### ("Heavy Ion Cancer Treatment" to overcome "Cancer"[18])

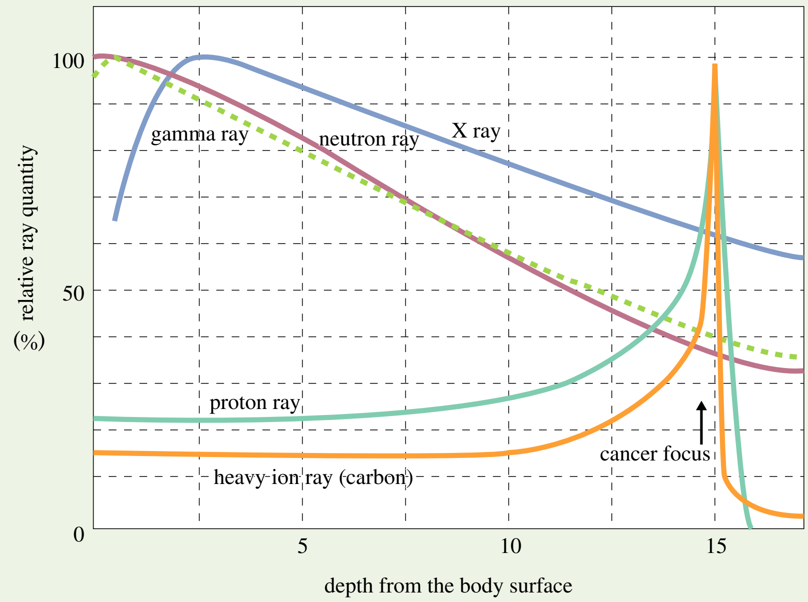
In 1993, the world's first heavy-ion cancer treatment equipment (HIMAC, or Heavy Ion Medical Accelerator in Chiba)[19] was built, and 3,178 patients received cancer treatment between the beginning of its clinical trial in 1994 and the end of 2006.

Treatment by radiation has advantages such as not burdening the patients because neither anesthesia nor surgery by incision is necessary. In heavy ion cancer treatment, in particular, the concentration of the beam is so high that interference to benign systems can be kept minimum by aligning the beam peak right to the cancer-damaged spot; in addition, because the heavy ion beam has a powerful ability to annihilate cancer cells, it is expected that even types of cancer that could not have been sufficiently eliminated by conventional radiation can be treated this way (Figure 7).

The National Institute for Radiological Sciences began doing research and development in technologies that would lead to size reduction, with the goal of having heavy ion cancer treatment equipment all over the country; their result has made it possible to obtain a beam with a performance equivalent to the current beam performance, with equipment about 1/3 of the size of the HIMAC. With this success, in 2006, Gunma University began building a small-size trial unit.

[18] Heavy ions refer to particles larger than protons; at the National Institute of Radiological Sciences, carbon rays are used.
[19] HIMAC (Heavy Ion Medical Accelerator in Chiba): heavy ion cancer treatment equipment

■ **Figure 7 Comparison of various types of radiation and heavy ion radiation**




Source: National Institute of Radiological Sciences

### (Detecting infectious diseases)

In February 2003, in the province of Guangdong of China, 305 people were infected with an acute respiratory illness, and 5 of them died. The cause was the SARS (Severe Acute Respiratory Syndrome) corona virus.

Under these circumstances, a research group led by Hiroshi Yoshikura, the director-general of the National Institute of Infectious Diseases of the Ministry of Health, Labour and Welfare, carried out the project “Urgent Research Study on the Diagnostic and Testing Methods of SARS.” They developed a method for detecting the SARS virus and a method for identifying a viral respiratory infectious disease.

The SARS test sample developed in this project is able to detect the virus within 20 minutes; it was jointly developed by Prof. Koichi Morita (Institute of Tropical Medicine, Nagasaki University), Dr. Masato Tashiro (National Institute of Infectious Diseases), and Eiken Chemical Co., Ltd.

### (Overcoming lifestyle-related diseases - development of medicine to lower the cholesterol level)

Coronary artery diseases (cardiac arrest, cardiac infarction, etc.) due to a high blood-cholesterol level are becoming a very serious type of illness in Japan, second only to cancer. The development of “statin drugs[20],” later referred to as the “penicillin of arteriosclerosis and cholesterol,” was aided by significant contribution of the research results of Dr. Akira Endo (currently the director of the Biopharm Research Laboratories, Inc. and professor emeritus of Tokyo University of Agriculture and Technology).

[20] “Statin” refers to any substance that lowers cholesterol in the blood (an anti- cholesterolemic agent). According to fundamental clinical research in recent years, statin is proved effective for Alzheimer's disease and osteoporosis as well.

Dr. Endo, after graduating from Tohoku University, began doing research at a pharmaceutical company in 1957. After his 2-year experience of studying in the United States (at the Albert Einstein College of Medicine in New York as a postdoctoral researcher), he moved on to the Tokyo University of Agriculture and Technology in 1979, and there discovered a substance called "Manacolin K" (a.k.a. mevinollin, lovastatin) from a mold (fungus) called "*Monascus purpureus*" (beni koji mold, red malt mold)[21]. About the same time, the same substance was discovered from a different fungus by the U.S. pharmaceutical company Merck. The discovery of this substance was a breakthrough, leading to speedy advancement in the development of statin drugs afterwards.

Sales of statin drugs began in 1987 in the United States and 1989 in Japan.

### (Medicines made from "immunology," a strength of Japan)

Medicine that uses the operation of the defense system called "immunity," with which human bodies are equipped, is called antibody medicine.

Tocilizumab (humanized anti-human interleukin-6 (IL-6) receptor antibody)[22] is an antibody medicine originated in Japan, and it is the world's first IL-6 inhibitor. Results of basic research conducted at Osaka University led to the invention of a medicine against Castleman's disease[23] in 2005 through subsequent collaboration with Chugai Pharmaceutical Co., Ltd. At present, this medicine is going through a clinical study for its effectiveness in "joint rheumatism."

In 1986, Prof. Tadamitsu Kishimoto discovered the genes of IL-6 for the first time in the world. Chugai Pharmaceutical Co., Ltd., which was doing research on antibodies against lymphocytes, began its collaborative research with Osaka University, and joint work also began with the MRC National Institute for Medical Research in UK. Then Prof. Kazuyuki Yoshizaki, et. al. discovered that Castleman's disease is caused by IL-6, and clinical trials were carried out by Prof. Norihiro Nishimoto, et. al. All these events led to the development of the first antibody in Japan.

At Osaka University, there is a powerful school of immunology research; there is an accumulation and succession of knowledge, beginning with Prof. Yuichi Yamamura, a former president of the university, a pioneer in cancer immunity treatment, and the first president of the Japanese Society for Immunology, going down to Prof. Kishimoto, and, more recently, Prof. Akira. The knowledge and accumulation of the basic research on lymphocytes and immunity done by Prof. Kishimoto led to the prediction of the existence of IL-6, which was yet unknown. Then Dr. Toshio Hirano (currently a professor at Osaka University), without any of today's high-performance analyzing equipment, isolated the IL-6 genes after 8 years of hard work; this achievement provided the most crucial key to the success. Then, the production of a mass culture of antibodies, which is a technological strength of a corporation, enabled the clinical trial.

This is an example where the "knowledge" and "people" developed by basic research enabled the research results to make their way back to society through collaborative research with a company.

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[21] Red malt has been used as health food since ancient times in China. It is used in red bean curds, Chinese white liquors (*shaoxingjiu*), vinegar, and food additives (red coloring), as well as Chinese medicine.

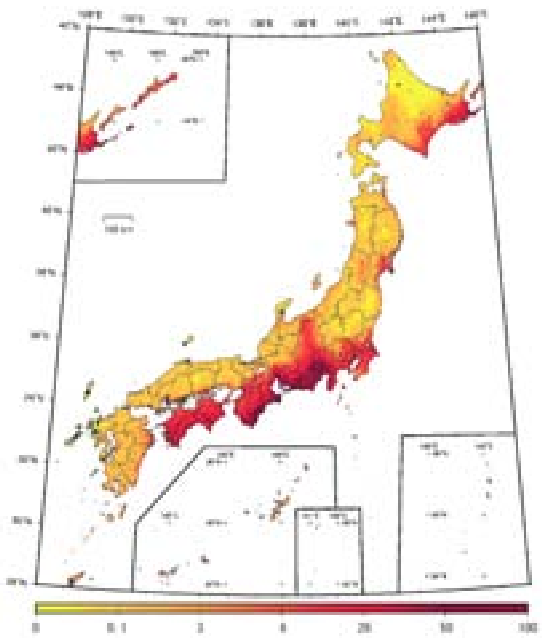
[22] Interleukin (IL) is a protein secreted by white blood cells and is a substance with an immunity function. To date, over 30 types are known. Among them, IL-2 is used for immunity treatment for cancer.

[23] Castleman's disease is a lymphoproliferative disorder with about 1500 patients in Japan. The medicine for its treatment is designated as an orphan drug under the Pharmaceutical Affairs Law.

Column 3: “Toward a Safe and Secure Society”

1. “Seismic Prediction Map” (introducing the Probabilistic Seismic Hazard Map of Japan, created by the Headquarters for Earthquake Research Promotion, in which all predicted earthquakes in the future are taken into account and the quakes in every square kilometer of every part of the Japanese islands are predicted)

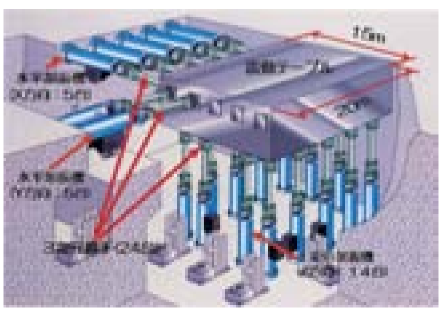
Probabilistic Seismic Hazard Map of Japan



Probability (%)

Source: Headquarters for Earthquake Research Promotion

2. “Earthquake resistance experimental research using E-defense” (introducing the 3-dimensional full scale earthquake testing facility (“E-Defense”) of the National Research Institute for Earth Science and Disaster Prevention, which is capable of simulating damage and collapse of structures by applying powerful shaking to the actual structures)



E-Defense earthquake table

Wooden-house collapsing experiment

Source and photo provided by the National Research Institute for Earth Science and Disaster

3. “Daichi,” Advanced Land Observing Satellite (ALOS) (Introducing “Daichi” (ALOS), an advanced land observing satellite developed by the Japan Aerospace Exploration Agency and launched on January 24, 2006, on H-IIA rocket 8 at the Tanegashima Space Center)

4. Japan's space technology found in everyday life - spin-off (examples of how technologies originally developed for space are used in our daily lives (spin-off; technology transfer))

■ Ignition technology for solid rockets
⇒ applied in airbags by Nissan Motors, Co., Ltd.
■ Structure design technology for weight reduction and enhanced strength for rockets, etc.
⇒ diamond-cut cans by Toyo Seikan Kaisha, Ltd. ("Hyoketsu," a canned liquor by Kirin Brewery Co., Ltd.)
■ Heat insulator technology for rocket tip
⇒ insulator coating for construction
■ Washing technology for space
⇒ washing machines
■ H-II rocket joint technology
⇒ Seismic-isolation multilayer rubber bearings
■ Sensor technology for each observation satellites
⇒ sugar content sensor for fruits
■ Explosion blast propagation simulation program in rocket launching
⇒ the engine (leading) vehicle design in linear-motor cars and bullet trains

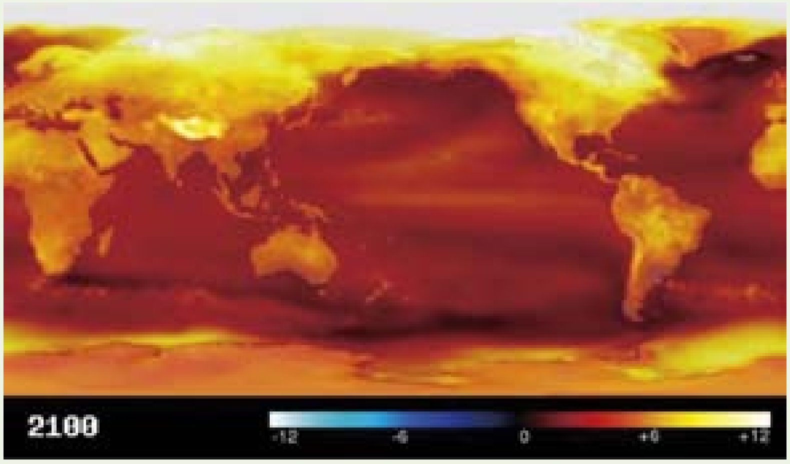
## (2) Harmony between human activities and the earth's environment

### (Future prediction of the earth's environment by the Earth Simulator, etc.)

The Earth Simulator is a supercomputer with the highest level of computation capabilities in the world as of the time of the commencement of its operation, which was 2002.

Various conditions of the earth can be simulated by the Earth Simulator. In particular, its simulation of global-level climate changes has contributed significantly to the research in the field of global environment. The Fourth Assessment Report (February 2, 2007) of the United Nations' "Intergovernmental Panel on Climate Change" (IPCC) quoted many of the results of Japanese researchers that have used the Earth Simulator, including "Calculations to Predict Global Warming to A.D. 2100," carried out by Profs. Akimasa Sumi and Masahide Kimoto of the Center for Climate System Research at the University of Tokyo, Dr. Toru Nozawa of the National Institute for Environmental Studies, and Seita Emori, the group leader of the Frontier Research Center for Global Change at JAMSTEC (Figure 8).

■ **Figure 8 Simulation results of global warming 100 years from now**




Sources: Center for Climate System Research at the University of Tokyo, National Institute for Environmental Studies, Frontier Research Center for Global Change

### (Photovoltaic power generation)

To address global warming, it is urgent to further promote science and technology related to the environment, energy, and resources. To this end, the importance of R&D in photovoltaic power generation is ever increasing.

Practical implementation of solar cells did not begin until 1954, when silicon solar cells were developed in the U.S. They were first used in Japan in 1958, but it was not until the mid 1960s when their mass production was planned. Incidentally, the generating efficiency of the silicon solar cells developed in the U.S. was about 6% whereas the efficiency of solar cells now is about 12 to 15%. It is said that theoretically an efficiency of 30% could be attained.

In 1993, “the New Sunshine Plan” was begun, in which the New Energy and Industrial Technology Development Organization promoted R&D on common basic technology for photovoltaic power generation systems and cost reduction of photovoltaic power generation. As a result, they advanced the technology that allowed them to reach the target, “keeping the manufacturing costs at 140 yen or less per watt,” which they had hoped to reach by year 2000. Through these technology-developing projects, Japan now has about half of the production share of the world’s solar cells.

## (3) Toward more convenient and pleasant daily life

### (Realization of large-capacity memory units by perpendicular magnetic recording system)

With increased storage capacities of hard disk drives (HDDs), it is now possible to record a long TV program; with smaller, lighter video players, we can carry the images around and enjoy them anywhere. Notebook PCs are getting even smaller and lighter. Our lifestyles are thus changing drastically.

It was thought that the longitudinal magnetic recording method used in conventional HDD units would soon push the HDDs to their limits in terms of increasing their capacities and reducing their sizes and weights.

It is said that the perpendicular magnetic recording method can break these limits and increase the capacity beyond 8 times as much as the conventional longitudinal magnetic recording method can. This method is already in use by Japanese companies to make 2.5-inch HDD units in the class of 200 gigabits per square inch.

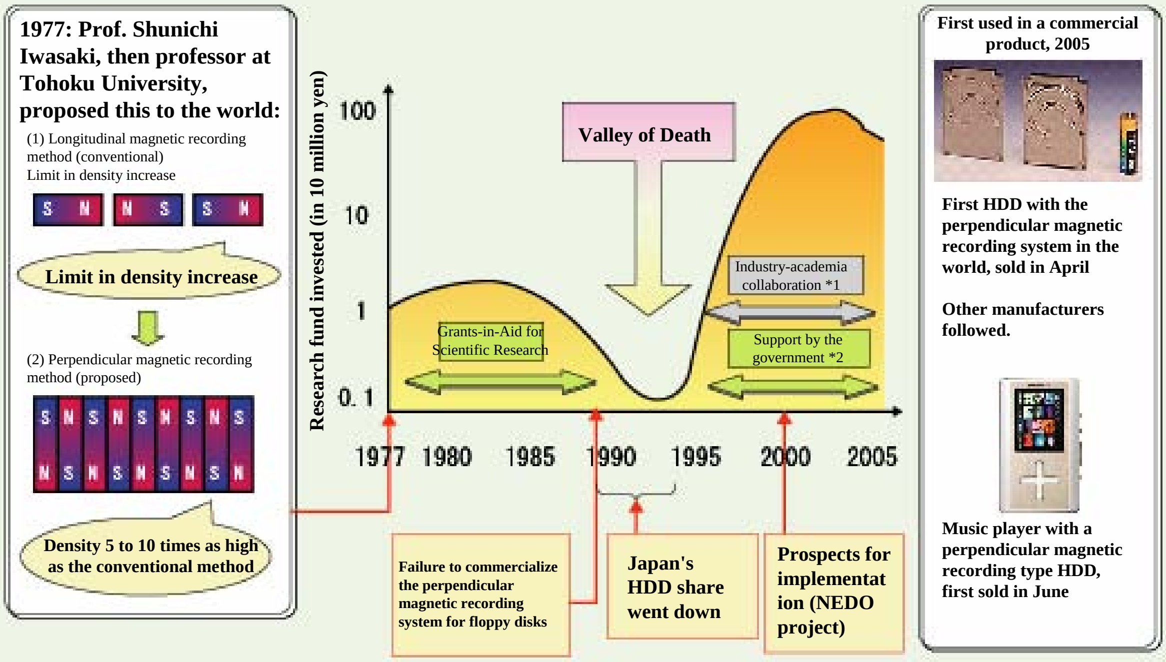
Prof. Shunichi Iwasaki, who at that time was professor at Tohoku University, began his research on magnetic storage back in 1951. In 1977 he announced the high density of the perpendicular magnetic recording system in an international conference; this attracted a lot of attention as a future technology. However, partly because its implementation was originally attempted for flexible disks[24], there was a period of uncertainty between the late 1980s and the early 1990s. In 1989, Prof. Iwasaki retired, at which time the research at Tohoku University was inherited by Prof. Yoshihisa Nakamura (currently of the Japan Science and Technology Agency), who had been supporting Prof. Iwasaki up to that time. He switched the research to a research project on HDD using the perpendicular magnetic recording system, but the technology of HDD using the longitudinal magnetic recording method continued to be improved, even leading some to conclude that the perpendicular magnetic recording method is unnecessary. The break came around 2000. When the conventional method actually approached its limitations, students taught by Profs. Iwasaki and Nakamura finally implemented the perpendicular magnetic recording method in the private sector. This triggered a rapid increase in the HDD market, which was about 2.5 trillion yen in 2004 but is expected to be as much as 6 trillion yen in a few years. All HDD units are very likely going to be replaced with those using the perpendicular magnetic recording method.

Throughout this period, public funding continued. During the 1970s and 80s, when Prof. Iwasaki proposed the new method, there was continual support for basic research by the university and public funding such as Grants-in-Aid for Scientific Research. At some points, the advancement in the longitudinal magnetic recording method questioned the need for implementing the new method, leading even to the opinion that it is unnecessary; however, the basic research funding by the university went on without ceasing, supporting the research. The innovative value of the perpendicular magnetic recording method was still highly recognized even after that time, and the research received support from various sources, including industry-academia-government collaboration, the Japan Society for the Promotion of Science, the New Energy and Industrial Technology Development Organization, and the “IT Program” by MEXT (Figure 9).

When the longitudinal method reached its limits, the need for HDD using the perpendicular magnetic recording method skyrocketed. Finally in 2005, a domestic HDD manufacturer began making products using this technology. One can thus say that this technology saw its fruition because of the significant contribution made by long-term public funding.

[24] Generally, these are referred to as floppy disks (FDD), but the JIS uses this term.

**■ Figure 9 Public funding that supported the perpendicular magnetic recording method: "through the valley of death"**




*1 SRC: Storage Research Consortium (interested parties in the industry and Tohoku University) (1995-)
*2 NEDO (New Energy and Industrial Technology Development Organization) of METI (1996-2002), Japan Society for the Promotion of Science (1999-2003), and MEXT (2002-2007)
Prepared by the Council for Science and Technology Policy of the Cabinet Office (Council for Science and Technology Policy 47th session, June, 2005) based on sources from Prof. Yoshihisa Nakamura of Tohoku University

### (Practical use of blue light-emitting devices)

Modern traffic lights which use LEDs (Light Emitting Diodes) allow the lights to be distinguished clearly and significantly reduce the consumption of power.

LEDs are also introducing many other new products such as large outdoor color displays and cellular phones with color liquid crystal displays, continuing to cause big ripple effects in our society economically and socially.

Regarding the three primary colors[25], red and green LEDs were already in use in various aspects of our daily lives by inventions of people such as Jun-ichi Nishizawa, then professor at Tohoku University. However, the last of the three colors, blue LED, was extremely difficult to produce, and its implementation had long been anticipated. Eventually various researchers and research groups, independently, made progress toward this goal, including a group led by Prof. Isamu Akasaki and Prof. Hiroshi Amano (of Nagoya University at the time), Mr. Takashi Matsuoka, a researcher in the private sector (a researcher at the NTT Basic Research Center at the time; now at Tohoku University), and Dr. Shuji Nakamura (of Nichia Corporation, Ltd. at the time).

There were two candidates for blue LEDs: zinc selenide and gallium nitride. While most researchers chose the former, it was the researchers who gambled on the possibility of gallium

[25] The three primary colors for light are red, green, and blue. All colors are combinations of these three. Mixing all of these colors, red, green, and blue results in white (color of solar light and a fluorescent light).

nitride, of which high-quality crystals were difficult to make, that eventually produced the revolutionary result.

For this accomplishment, Dr. Nakamura won the Millennium Technical Prize, awarded with support of the government of Finland in 2006.

The Japan Science and Technology Agency summarizes the economic ripple effect of the contracted development project "Manufacturing technology for gallium nitride (GaN) blue LEDs" as follows. During the 9-year period from 1997 to the end of 2005, the total sales of application products reached approximately 3.6 trillion yen. As direct results, this has created almost 350 billion yen of add-on value to the industry of Japan and about 32,000 new jobs. It also brought in royalty revenues of approximately 4.6 billion yen to the government.

Column 4: "Carbon nanotube: a new material that will change the society" (discovery of carbon nanotubes and carbon nanohorns by Dr. Sumio Iijima (Special Senior Researcher at NEC, Professor in the Faculty of Science and Technology, Meijo University), introduction of "Drug delivery system (DDS) directly attacking cancer cells using carbon nanohorns with anticancer drugs," a joint project of NEC, Cancer Institute of the Japanese Foundation for Cancer Research, and the Japan Science and Technology Agency)

## 2 Industry-academia-government collaboration: a key to application of science and technology results

### (1) Industry-academia-government collaboration steadfastly planted

By the promotion of policies regarding industry-academia-government collaboration based on the Second Science and Technology Basic Plan, accomplishments of joint research by universities and companies have drastically increased; the number of joint research projects at national universities, etc. in 2005 exceeded 13,000 if all national, public, and private universities are combined. The total amount of research funds given to universities, etc. by research institutions was 32.3 billion yen in 2005, the highest amount ever.

The number of contract research projects at national, public, and private universities, etc. was 16,960, with 126.5 billion yen in contract research projects fees, both numbers being highest in history. Meanwhile, during the 5-year period covered in the Second Basic Plan, the number of patent applications submitted by national universities, etc. grew to about 10 times the number at the beginning of the period, indicating a remarkable accomplishment.

### (2) Examples of results of industry-academia-government collaborative research

#### (Metallic glass)

Metallic glass is a metallic material created in Japan. It is different from metal, which has a crystal structure, in that the atomic configuration is "random and dense"; it is a revolutionary metallic material which is strong, flexible, rust-resistant, smooth-faced, and easy to fabricate.

This field of research was initiated by a group led by Dr. Akihisa Inoue, then director of Tohoku University's Institute for Materials Research and currently president of Tohoku University. Many metallic glass materials were discovered in the 1980s, and researchers found the conditions under which metals change to glass, the structure of metallic glass, and its properties in the 1990s.

Later this topic was selected to be a project by the New Energy and Industrial Technology Development Organization. The micro-geared motor was developed through a joint project of the Institute for Materials Research at Tohoku University, R&D Institute of Metals and Composites for Future Industries (RIMCOF), Namiki Precision Jewel Co., Ltd., and YKK Corporation. A type of pressure sensor was also developed through a joint project of the Institute for Materials Research at Tohoku University, RIMCOF, Nagano Keiki Co., Ltd., and YKK Corporation.

#### (Development of intelligent emission catalyst for automobiles)

The automotive emission standards have become more restrictive since the 1990s around the world, drastically raising the price of palladium, which is used as a catalyst. An “intelligent catalyst” self-regenerates palladium (the catalyst) as the vehicle is driven. The depletion of palladium is extremely small, and the performance in purifying the exhaust gas does not deteriorate, thus greatly reducing the amount of palladium used.

The self-regenerating function of an intelligent catalyst was discovered by Dr. Hirohisa Tanaka, et. al. of Daihatsu Motor Co., Ltd. in the 1990s. Together with Dr. Yasuo Nishihata of the National Institute of Japan Atomic Energy Development, they explained the principle of the self-regenerating mechanism using a large synchrotron radiation facility called SPring-8.

Trial calculations showed that over 100 tons of precious metals for automotive catalysts can be saved per year, so the prices of precious metals are expected to stabilize.

### (3) Project to create knowledge clusters

A “knowledge cluster” refers to a technology-innovation system directed under a regional initiative, centered on a public research institution such as a university, with participants coming from in and out of the region, including companies. The seeds of the public research institution and the companies’ need for implementation are joined, enabling new industries to be created. A project to create these knowledge clusters was carried out in 18 regions across the nation as a five-year project of MEXT from 2002 to 2006 (12 regions in 2002 when it began).

#### (Involvement in regional science and technology promotion in the Hamamatsu area)

In the “knowledge clusters creation project” of the Hamamatsu area, active efforts are made to train coordinating human resources, led by the Organization for Hamamatsu Technopolis, the core institution. Science and technology coordinators, well familiar with the regional collaboration situations, use their information and human networks in “imaging technology project research consortium” that are held to provide an organic meeting place of the industry, academia, and government. This type of coordination of a structure necessary for the project’s collaboration and thorough progress management are bringing forth solid advancement in the collaboration. Through human-resource training that promotes the region, for instance, by involving the region’s technical high schools (not just universities), the project is having extensive influence on the greater

Hamamatsu area.

### (Detailed inspection of metal materials by X-ray)

The first result of the industry-academia-government collaboration under the knowledge clusters creation project in the Hamamatsu area was the “X-ray imaging device equipped with the energy-identification function,” a result by an industry-academia collaborative project by Dr. Yoshinori Hatanaka of the Research Institute of Electronics, Shizuoka University (at the time), Dr. Toru Aoki, and Hamamatsu Photonics K.K.

By detecting the difference in the X-ray energy going through an object or a material, this allows one to identify very small bumps and dents on the metal surface and in the internal structure for each material, thus contributing to increased reliability and accuracy in non-destructive inspection. In addition, an imaging device that measures the wavelength difference of the penetrating X-ray and indicates it using colors was developed as a product.

# Section 4 ■ Development of Next-Generation Human Resources - Succession of Knowledge -

## 1 Importance of development and retention of science and technology-related human resources

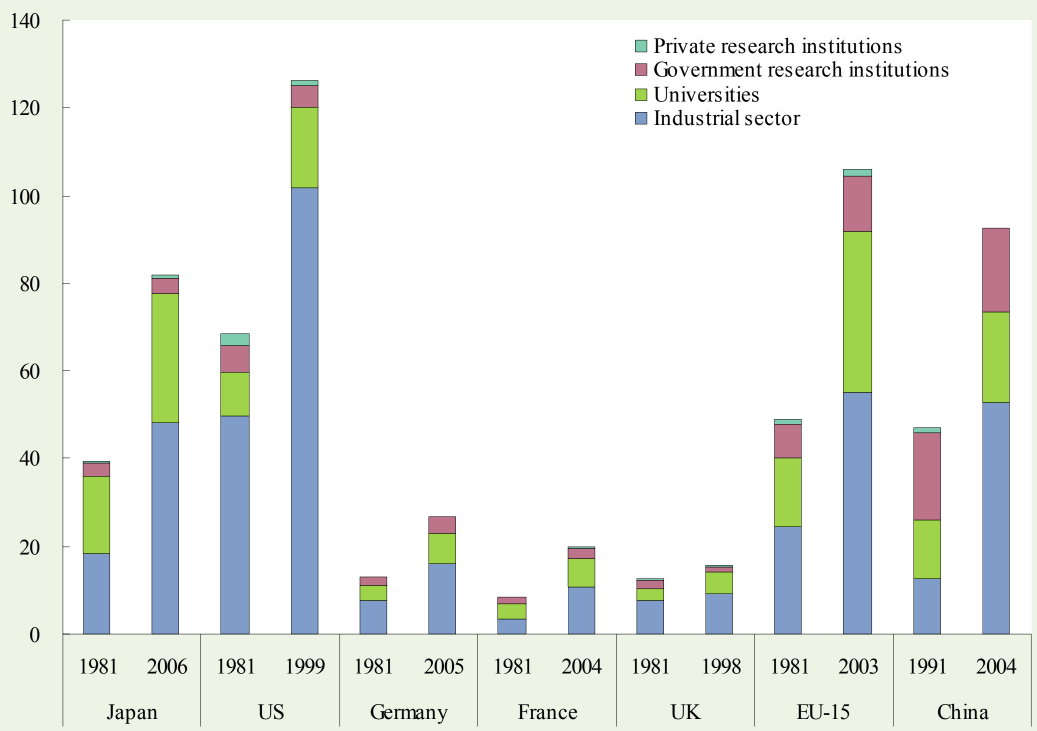
The Third Science and Technology Basic Plan features as a basic tenet "Emphasis on fostering human resources and competitive research environments – Shift of emphasis from 'hard' to 'soft' such as human resources; greater significance of individuals in institutions" and points to the need to shift emphasis to investment intended to develop and utilize excellent human resources.

### (1) Other countries' efforts to develop and secure human resources

The numbers of researchers in Japan and other countries have now risen sharply compared with the early 1980s, indicating that the role of researchers as the core human resources in the establishment of a knowledge-based society is expanding (Figure 10).

In this context, countries around the world regard the development and retention of excellent human resources as the centerpiece of their science and technology promotion policies and are implementing a variety of initiatives suited to their own circumstances and challenges.

■ **Figure 10 Trends in number of researchers in Japan and other major countries**

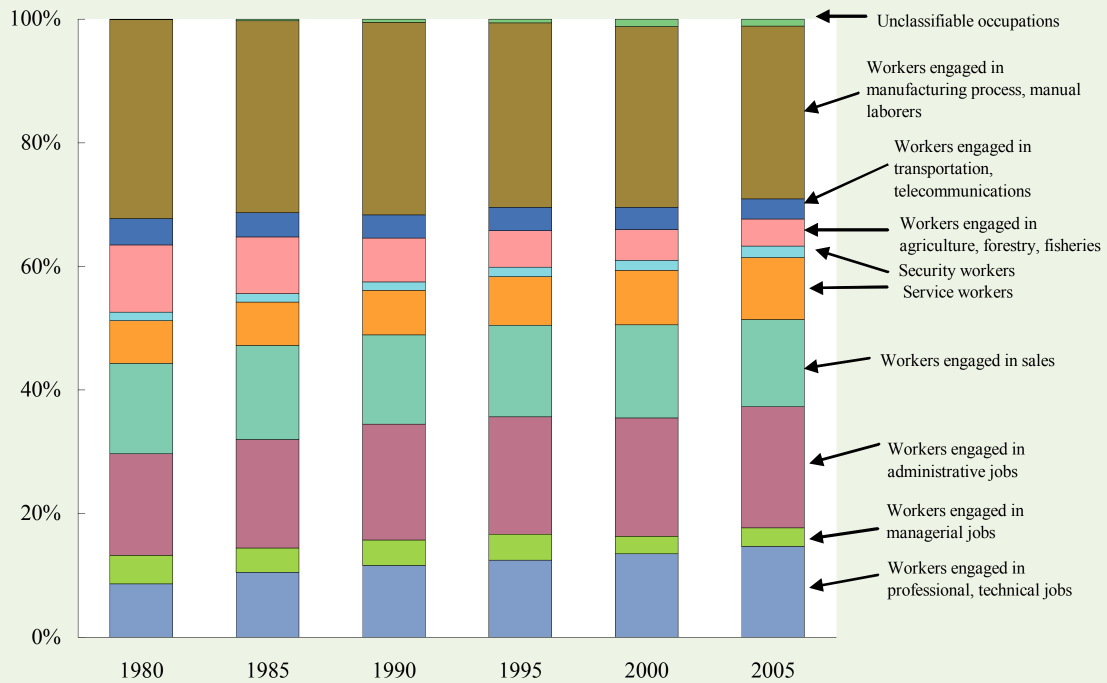



Note: EU-15 comprises Belgium, Germany, France, Italy, Luxemburg, Netherlands, Denmark. Ireland, UK, Greece, Portugal, Spain, Austria, Finland and Sweden.
Source: Figures for Japan taken from "Report on the Survey of Research and Development" by the Ministry of International Affairs and Communications and those for other countries from "Main Science and Technology Indicators" by the OECD.

## (2) Japan's viewpoint concerning human resource development and retention

The number of researchers in Japan stood at 820,000 in fiscal 2006, rising more than double from 395,000 in 1981. It is notable that the ratio of researchers working in the industrial sector to the total number of researchers increased particularly sharply (Figure 10). Moreover, the ratio of people engaged in professional and technical jobs, including science researchers and engineers, to the total number of workers has been rising in Japan in recent years (Figure 11).

■ **Figure 11 Percentage breakdown of employees by occupation type**

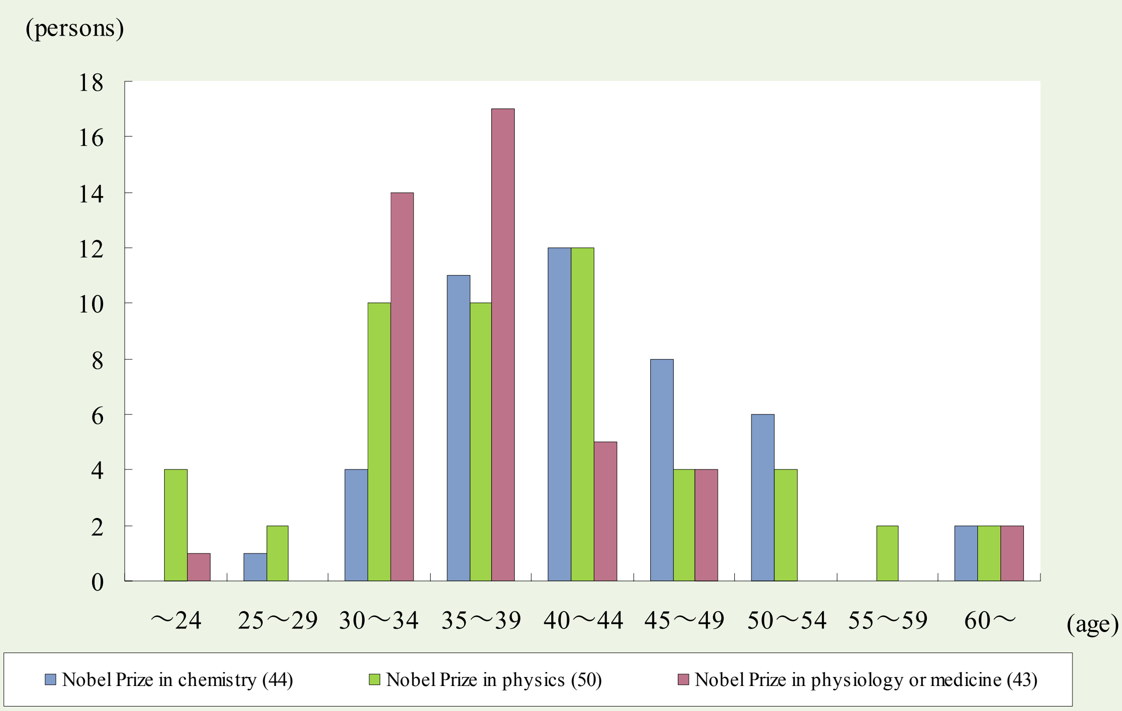



Source: 2006 White Paper on the Labour Economy by the Ministry of Health, Labour and Welfare

In order to ensure the development and retention of human resources capable of supporting Japan's intellectual foundation, it is important to provide young researchers, who are the key to this challenge, with a variety of research opportunities suited to their aptitudes. It is thus desirable to further enhance programs for assisting young researchers in the future.

A survey on at what age Nobel laureates did the work for which they were commended shows that Nobel prize-class achievements are mostly attained when the scientists are in their 30s to 40s (Figure 12).

**■ Figure 12 Distribution of Nobel Prize laureates by age of prize-winning work (1987-2006)**




Note: The "age of prize-winning work" indicates the age of the Nobel laureate at the time of the publication of the research paper, etc. that led to the award. The following principles were applied to determine the age.

1) The age of the prize-winning work shall be equivalent to the number reached by deducting the number of the year of the Nobel Laureate's birth from the number of the year when the research paper, etc. that led to the prize award was published.
2) When two or more papers were cited in the commendation, the year when the earliest one was published shall be used in the calculation explained above.
3) When the publication date of the paper, etc. that led to the prize award cannot be precisely determined, the year of the prize-winning work shall be assumed as follows: Work done in the 1990s shall be dated to the year 1995, work done in the early 1990s to 1992, work done in the latter half of 1990s to 1998 and work done in the mid-1990s to 1995.

Source: Survey by MEXT

## 2 Results of human resource development conducted through research activities

Research activities at university are conducted as one with education.

Education and research activities have the function of not only training academic researchers but also developing human resources capable of playing an active role in various sectors of society.

### (1) Reform of graduate schools

Against the background of the diversification of social needs and the realization of a borderless economy and a society based on advanced communications technologies, demand has grown for human resources equipped with advanced expert knowledge and abilities and capable of playing an active role across national borders. Reform of the graduate school system has been vigorously promoted in order to help to diversify the methods and arrangements of education, leading to the establishment of new types of institutions such as graduate universities, the injection of flexibility into the university entrance criteria and the duration of academic programs as shown by the adoption of an early entrance system and the adoption of the Graduate School Coordination Program. The number of graduate school students in Japan has risen about 3.5 times over the past 20 years, although the number is still small compared with the numbers in the United States and Europe.

In recent years, Japanese universities have also been promoting reform measures such as public invitations of research proposals throughout the campus with the use of the president's discretionary expenses of the university president and other measures for prioritized allocation of funds, the provision of support for young teaching staff and the introduction of arrangements for enabling flexible implementation of research programs.

Meanwhile, some universities seek to enhance assistance for young teaching staff and graduate school students by earmarking funds for research assistantship or by introducing a system of commending young teaching staff with innovative ideas and allocating to them research funds.

Besides, some research organizations have started collaborating with other institutions after establishing internal committees and organizations in charge of such collaboration.

The above-mentioned reform measures have contributed to the revitalization of education and research activities at universities and the development and retention of human resources that form the basis of science and technology and academic activities.

### (2) Fostering young researchers

#### (Support for post-doctorals)

Young researchers' experiences as post-doctorals[26] are important for fostering their creativity and independence. A survey conducted on the managers of universities and other research organizations show that many respondents characterized the post-doctoral period as the gateway to

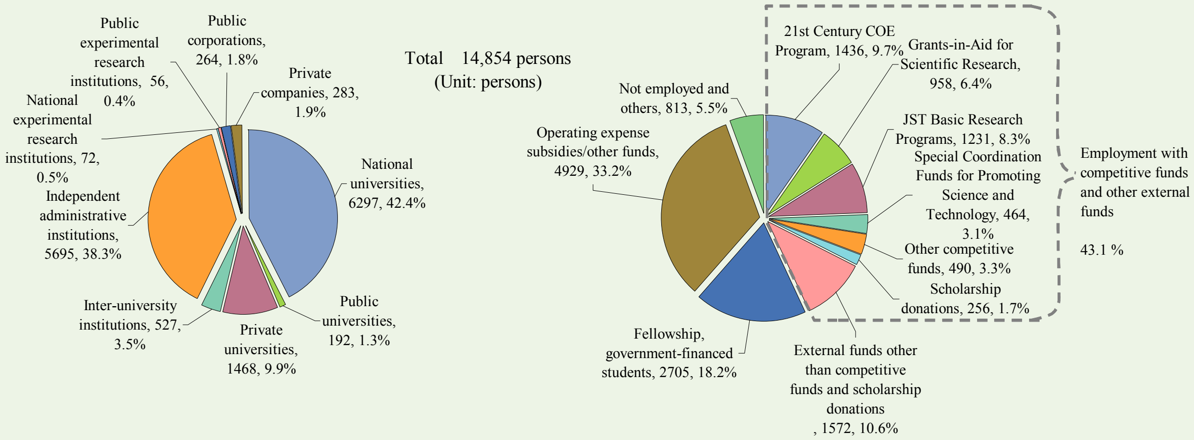
[26] Post-doctorals: Those who, after having completed doctorates, (1) engage in research activities at a research organization such as a university, not as a professor, an associate professor, an assistant professor, or the like, or (2) engage in research activities at a research organization such as an independent administrative agency, assigned to the position for a fixed term and are not in a position such as a leader or a senior researcher of their research group. Both (1) and (2) include those who have terminated their student status but have been a graduate student for a period exceeding the required number of years for completing a doctoral course and have obtained the required credits (generally referred to as "withdrawals upon obtaining required credits").

independence for young researchers or an opportunity to broaden the range of their research.

On the other hand, as the uncertainty over the career paths of post-doctorals remains a problem, it is important to enhance the transparency over the process of employing young researchers, help them become independent and promote career-support efforts, such as providing post-doctorals with career options other than academic research jobs.

According to a survey conducted by MEXT in fiscal 2005, a total of 14,854 post-doctorals and the like were employed as of fiscal 2004, with 57% of them working at universities and 38% at independent administrative institutions. The breakdown by the type of funding showed that 43% were supported by competitive funds and other outside funds and 33% by operating expense subsidies and other internal funds (Figure 13).

■ **Figure 13 Employment status of post-doctorals by type of institution and funding**




Source: "Survey on Postdoctoral Fellows and Research Assistants (FY2005) August 2006" by National Institute of Science and Technology Policy/MEXT

### (Enhancing Quality of Young Researchers through JSPS Research Fellowships for Young Scientists)

The JSPS Research Fellowships for Young Scientists (sponsored by the Japan Society for the Promotion of Science) is intended to provide talented young researchers in Japan with opportunities to devote themselves to research activities concerning themes selected by themselves with a free mind in order to foster and retain researchers. In fiscal 2006, as many as 5,032 researchers were adopted as fellows. This program has contributed to remarkable improvement in the capabilities and potentials of promising, next-generation researchers by attaching importance to the independence of such researchers so as to enable them to devote themselves to research activities.

With regard to the employment status of researchers adopted as fellows under JSPS Research Fellowship (PD), about 40% obtained permanent research jobs immediately after the completion of their fellowship term, with the ratio rising to about 50% one year later, to 70% four years later and to more than 80% 10 years later.

Column 5: “Liberal Research Environment and Consistent Support are Important for Fostering Young Researchers” (Dr. Hiroshi Takayanagi, professor at Tokyo Medical and Dental University)

### (3) Cultivating uniqueness and international competitiveness of universities

Since fiscal 2002, MEXT has been implementing the 21st Century COE program, which aims to cultivate the uniqueness and international competitiveness of Japanese universities by providing targeted support for the establishment of world-top-class research and educational centers at Japanese universities so as to raise the standard of research and develop creative human resources capable of making world-leading achievements.

The following are the results of a questionnaire survey conducted in December 2005 on the presidents of all universities to which graduate schools are attached (There are 558 such universities.) regarding the 21st Century COE program and a survey conducted on the selected COE program leaders and committee members in charge of screening and evaluation.

○ More than 90% of COE program leaders and screening and evaluation committee members replied that the 21st Century COE program contributes to the revitalization of the education and research environment in Japan as a whole. The presidents of more than three quarters of all universities, including those that do not have projects adopted under the COE program, have replied that the program contributes to the revitalization of the education and research environment in Japan as a whole.

○ Many respondents said the 21st Century COE program has contributed to human resource development by playing a significant role in enhancing financial support, promoting internationalization, improving the education and research environment and raising the standard of research. Specifically, each COE has made efforts to promote research activities by students themselves, enhance students’ research motivation through experiences gained abroad, promote student exchange across the boundaries of the fields of majors and laboratories, provision of joint guidance to students on multidisciplinary fields based on teacher collaboration, and to cultivate internationality through the introduction of tasks such as writing papers and making presentations in English.

○ With regard to the enhancement of financial support, the number of students adopted as research assistants increased by 2.6 times at the selected COEs compared with when the application was made. In addition, the number of post-doctorals employed increased by 2.2 times. In particular, the number of foreigners employed increased by 2.6 times and the number of people employed from other research organizations increased by 3.2 times, facts that indicates that the 21st Century COE program is helping to improve the level of internationalization and the mobility of researchers.

○ With regard to improvement in the standard of research conducted by graduate school students and the level of internationalization, the number of research papers contributed to academic journals by doctorate course students at the selected COEs increased by 1.3 times from 12,000 to 16,000. About three quarters of those papers were contributed to refereed journals of global standards, indicating that high levels of research are conducted in doctorate programs. The number of presentations made at academic conferences increased by 1.3 times, with the number of those made at conferences held abroad rising as much as 1.5 times.

○ With regard the status of graduate school students after completing their courses, the number of graduate school students employed by R&D divisions of companies increased by 1.3 times compared with before the COE program, indicating that the program helped the development of human resources capable of contributing to industry.

○ With regard to the implementation status of joint research activities, the number of joint research programs with Japanese and foreign universities, research organizations and companies increased 1.5 times, indicating that industry-academia coordination and internationalization have proceeded in research activities.

Column 6: "Concrete Achievements of 21st Century COE Program" (Project for International Center of Research & Education for Materials, Tohoku University)

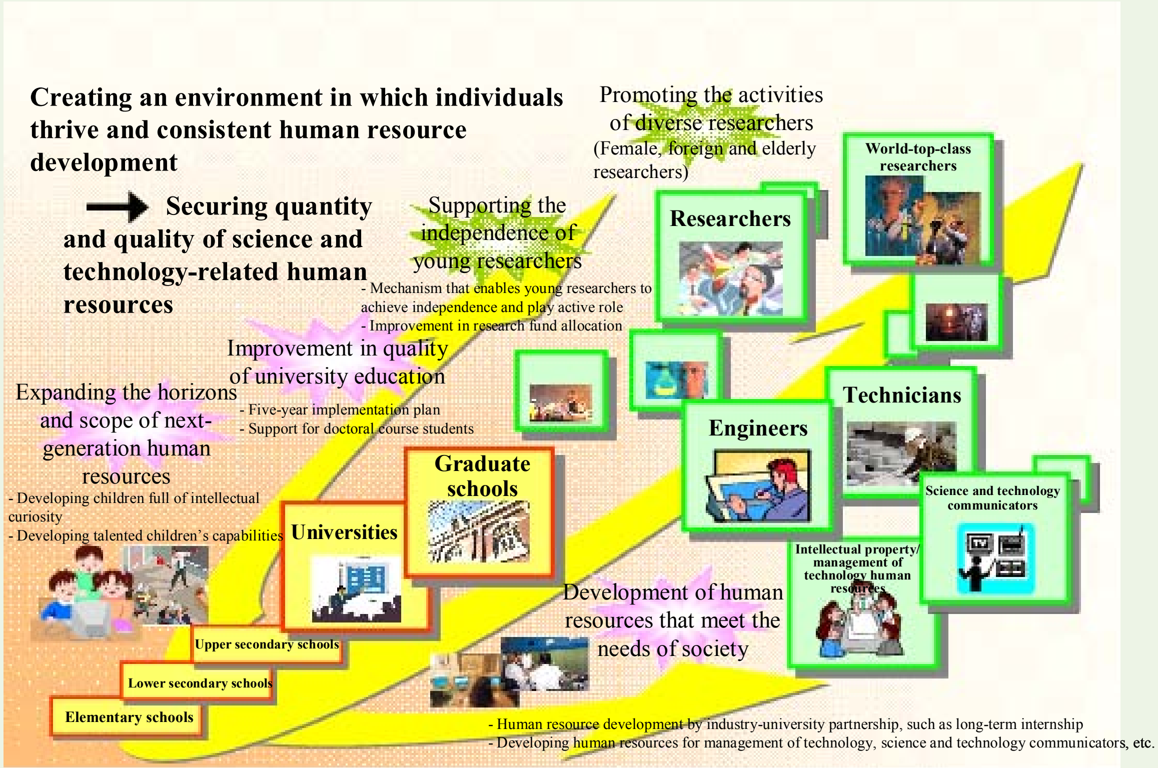
## 3 How to develop and retain human resources

Amid intensifying global competition for "knowledge," concern is growing about Japan's ability to secure sufficient human resources related to science and technology in terms of both quantity and quality as the country faces problems such as the aging of society and a population decline.

Therefore, it is a very important issue for Japan how to develop and retain human resources that form the basis of science and technology and academic activities and enable them to play an active role in various sectors of society.

The Third Science and Technology Basic Plan points out the importance of implementing consistent comprehensive efforts from elementary and secondary education to undergraduate/graduate courses in universities and adult education through the following measures: enhancing science and mathematics education, cultivating a favorable working environment for young researchers, female researchers and foreign researchers, strengthening the human resource development function of universities and human resource development by industry-university partnership (Figure 14).

■ **Figure 14 Development and securing of human resources and promotion of activity**




Source: MEXT

## (1) Support for independence of young researchers

### (Increase in competitive funds for young researchers)

In order to support young researchers who have made no notable achievement in the past but who are recognized as talented and capable of conducting research based on their own ideas, it is effective to set aside a certain proportion of competitive funds as a quota for young talents (Table 15).

In order to further enhance efforts to foster young researchers who can think flexibly and have a spirit that enjoys challenge, it is necessary to provide budding researchers with opportunities for becoming independent and venturing into new research areas, establish a system that allows further development of the capabilities of researchers who have made achievements by taking advantage of such opportunities and expand the amount of research funds intended for young researchers.

## ■ Table 15 Major competitive research funds for young scientists in Japan

| Competent Ministry | Distributing Organ | Program Name | | Target Researchers | Period |
|---|---|---|---|---|---|
| Ministry of Internal Affairs and Communications (MIC) | MIC | Strategic Information and Communications R&D Promotion Programme | Research and Development through Encouraging Researchers and their Collaborations (SCOPE-R) (Promotion of young advanced information technology researchers) | Up to age 35 | Up to 3 years |
| Ministry of Education, Culture, Sports, Science and Technology (MEXT) | MEXT/ Japan Society for the Promotion of Science (JSPS) | Grants-in-Aid for Scientific Research | Grant-in Aid for Young Scientists (S) | Up to age 42 | 5 years |
| | | | Grant-in Aid for Young Scientists (A) | Up to age 37 | 2 to 4 years |
| | | | Grant-in Aid for Young Scientists (B) | | |
| | | | Grant-in Aid for Young Scientists (Start-up) | Persons hired by a university, etc. as a researcher for the first time | 2 years |
| | | | Grant-in-Aid for JSPS Fellows | JSPS fellows | Up to 3 years |
| | MEXT | Special Coordination Funds for Promoting Science and Technology | Support Program for Young Fixed-Term Researchers | Fixed-term researchers up to age 35 | Up to 5 years during the fixed term |
| | | | Program to Create an Independent Research Environment for Young Researchers | Researchers who have earned a doctoral degree within the past 10 years | 5 years |
| | MEXT | Innovative Nuclear Research and Development Program | Nuclear Science and Technology | Up to age 40 | Up to 3 years |
| Ministry of Health, Labour and Welfare (MHLW) | MHLW | Health and Labour Sciences Research Grants | Promotion of young researchers | Up to age 37 | 1 to 3 years |
| | National Institute of Biomedical Innovation | Program for Promotion of Fundamental Research in the Health Science | Research by Young Individual Researchers Based on Creative Ideas | Up to age 37 | Up to 3 years |
| Ministry of Agriculture, Forestry and Fisheries (MAFF) | National Agriculture and Food Research Organization | Program for Promotion of Basic Research for Creation of New Technologies and Sectors | | Up to age 39 | 3 to 5 years |
| Ministry of Economy, Trade and Industry (METI) | New Energy and Industrial Technology Development Organization | Grant for Industrial Technology Research | | Under age 39 (Under age 44 for researchers of social sciences, etc.) | 4 years or 2 years |
| Ministry of the Environment (MOE) | MOE | Environmental Technology Development Fund | Feasibility study research area | Up to age 40 | 1 year |
| | | Environment Waste Management Research Grant | Promotion of young researchers | Up to age 35 | Up to 3 years |
| | | Global Environment Research Fund | Domain of innovative research | Up to age 40 | 1 to 2 years |

Reference Information: In addition to the programs shown in the table above, there is a program called "Precursory Research for Embryonic Science and Technology (PRESTO Type)" in the "Basic Research Programs" provided by the Japan Science and Technology Agency under the jurisdiction of the Ministry of Education, Culture, Sports, Science and Technology. It is not a system specifically targeting young researchers, but as a result of screening that did not take into account the researchers' backgrounds or accomplishments, the average age of the selected researchers was 36 (when selected in FY2006).

Source: Created by the Ministry of Education, Culture, Sports, Science and Technology based on materials prepared by the Cabinet Office

### (Creating an independent research environment for young researchers)

Although post-doctorals make great contributions to improving the standard of research in Japan and producing research results, they face problems such as instability of positions and uncertainty over their career path. In Japan, graduate school students are often employed as assistants after completing their graduate programs. While this system provides a certain degree of stability to the positions of researchers, it has been pointed out that it does not sufficiently ensure independence of young researchers or a competitive environment. Therefore, it is necessary to immediately implement personnel system reform at universities and other research organizations so as to establish a career path for post-doctorals and other young researchers, enhance the mobility of human resources and revitalize the research environment.

In fiscal 2006, Japan launched the Program Create an Independent Research Environment for Young Researchers (Special Coordination Funds for Promoting Science and Technology). This program seeks to establish a tenure track system (a mechanism for allowing young researchers to gain experiences as an independent researcher in fixed-term employment before obtaining a steady position through stringent screening) at Japanese research organizations aiming to become world-class research centers by supporting efforts to introduce a mechanism that provides young researchers with opportunities for becoming independent and making successful achievements in a competitive environment.

### (Enhancement of financial support for doctoral course students)

In order to encourage talented students to proceed to doctoral courses, it is necessary to cultivate an environment that enables them to devote themselves to academic and research activities without worrying about financial conditions.

According to a survey conducted by the Japan Student Services Organization on “FY 2004 Survey Results on Student Life” (April 2006), about 75% of the academic and living expenses of Japanese doctoral course students are covered by allowances provided by their families, scholarship funds and income from part-time jobs, etc. Figure 16 shows the current status of Japan’s financial support programs for graduate school students, including fellowship, teaching assistantship (TA), research assistantship (RA)[27] and scholarship. In the United States, meanwhile, many graduate school students are believed to receive non-repayable grant aid equivalent in amount to their living expenses through fellowship, research assistantship and other financial support programs.

The Third Science and Technology Basic Plan aims to enable about 20% of doctoral course (latter stage) students to receive financial support equivalent in amount to their living expenses. To do so, it is essential to enhance the JSPS Research Fellowships for Young Scientists program and implement financial support measures such as increasing the provision of competitive funds to students, expanding scholarship programs of the Japan Student Services Organization and exempting talented students from tuition fee payment.

[27] Fellowship: Fellowship aid is usually granted directly to students and is sometimes called a “portable subsidy” because the recipient students may engage in research at the graduate school of their own choosing with the use of the funds provided. Fellowship requires the recipients to devote themselves to research and attain excellent achievements, but the recipients do not have to return the funds.
Teaching assistantship (TA): Under the TA program, graduate school students are employed as assistants to the teaching staff of the university and receive a certain amount of grants in exchange for providing seminar guidance, giving instructions concerning experiments and practical training, implementing examinations and providing lessens to undergraduates.
Research assistantship (RA): Under the RA program, graduate school students are employed as assistants for the research activities of the teaching staff of the university and receive salaries and funds to cover tuition fees in exchange for assisting such activities.

## ■ Figure 16 Status of financial support for graduate school students

Grant type ← → / Loan type ← →

| Aid Type | Fellowship | Teaching assistantship (TA) | | Research Assistantship (RA) | | Scholarship |
|---|---|---|---|---|---|---|
| | | National universities | Private universities | National universities | Private universities | |
| Program | JSPS Research Fellowships (Japan Society for the Promotion of Science) | National university special account(Before FY 2003) | Recurring expense subsidies for private universities | National university special account(Before FY 2003) | Recurring expense subsidies for private universities | Scholarship programs (Japan Student Services Organization) |
| Budget | ¥8,254 million (FY2005) | ¥4,414 million (FY2003) | ¥1,500 million (FY2005) | ¥1,843 million (FY2003) | 800 million (FY2005) | ¥111.1 billion (FY2005) |
| No. of students aided: Doctoral degrees | 3,640 (Budgeted number in FY 2005) (5%) | 9,281 (Budgeted number in FY2003) (13%) | 9,091 (Budgeted number in FY2005) (4%) | 4,267 (Budgeted number in FY2003) (6%) | 678 (Budgeted number in FY2005) (1%) | 28,363 (Budgeted number in FY2005) (39%) |
| No. of students aided: Master's degrees/ Professional degrees | | 4,384 (Budgeted number in FY2003) (3%) | | | | 65,573 (Number under budget in FY2005) (38%) |

Note:
1. The percentage figures in parentheses in the column for the number of students aided represent the ratio relative to all students staying in the relevant programs at national, public and private universities (FY2004). (For reference: The total number came to 162,712 for students in master's degree programs, 7,866 for those in professional degree programs and 73,446 for those in doctoral programs (School Basic Survey 2004).
2. Students may receive two or more types of financial support in some cases.
3. TA and RA are funded not only by operating expense subsidies and recurring expense subsidies for private universities but also by the 21st century COE program.
4. The budget amount for RA at private universities includes financial support for post-doctorals.
5. Since FY2004, the expense of TA and RA against which measures are taken at the National university special account is transferred into the "national university budget subsidy" with incorporation and is operated at the discretion of each university corporation.

Source: MEXT

### (Developing human resources that meet the needs of society)

Japan, which aims to become an advanced science and technology-oriented nation, must enable doctorals to play an active role not only at universities and research organizations but also in various sectors of society by taking advantage of their advanced expertise. According to a comparison of data on the employment status of Japanese doctorals and the status of their U.S. equivalents as broken down by employment sector, the ratio of doctorals employed by commercial companies in the United States is almost double the ratio of Japanese doctorals employed by commercial companies.

Moreover, data on annual income by the type of degree earned shows that doctorals earn the most. Doctorals are highly appreciated at companies' R&D divisions in the United States, and such students employed by the industrial sector generally earn more than their equivalents hired by other employment sectors. This situation apparently provides a strong incentive for doctorals to obtain jobs at companies.

On the other hand, a survey by Nippon Keidanren's Committee on Industrial Technology[28] shows that most Japanese companies have no employment quota for doctorals and that they make employment decisions based on their evaluation of the abilities of individual applicants. Factors regarding which doctorals are recognized by companies as excellent include "expert knowledge/skills," "ability to conduct research" and "logical thinking capability." On the other hand, factors regarding which problems are recognized include "communications skills," "cooperativeness" and "ability to perform business procedures." Attributes companies expect in doctorals include "leadership," "task-setting capability," "management capability" and "spirit that enjoys challenges."

### (Human resource development by industry-university partnership)

Industry-university-government joint research not only provides ideal opportunities for young researchers to improve their research skills but also help to foster new research leaders.

In addition, in both university and industrial sectors, awareness is growing that there is a pressing need to develop "advanced expert human resources" capable of understanding the position of their areas of specialty in relation to social activities as a whole, setting tasks in light of practical problems and tackling them.

### (Promoting the activities of doctorals in industry)

Japan has been implementing the Project to Promote Diversification of Career Paths for Science and Technology-related Human Resources since fiscal 2006 in order to encourage people with advanced expertise such as doctorals to exercise their capabilities in various sectors outside universities and other research organizations providing organized support to and cultivate a favorable environment for young researchers with regard to career choice.

### (Expanding the horizons and scope of human resources)

In order to develop and retain next-generation human resources related to science and technology, it is important to provide opportunities to experience the wonder and delight of science and mathematics at elementary and secondary schools so as to foster interest in science and technology and develop the capabilities of highly-motivated and talented children, thereby expanding the horizons and scope of human resources.

To this end, it is necessary to implement a consistent set of measures such as: to expand opportunities for first-hand learning such as observation and experiments, promote communication between students and researchers/engineers, provide support to high schools that attach importance to science and mathematics education as well as to universities that provide special education programs to a selected group of highly-motivated and talented students.

[28] Results of Survey on Status of Doctorals at Companies (February 2007)

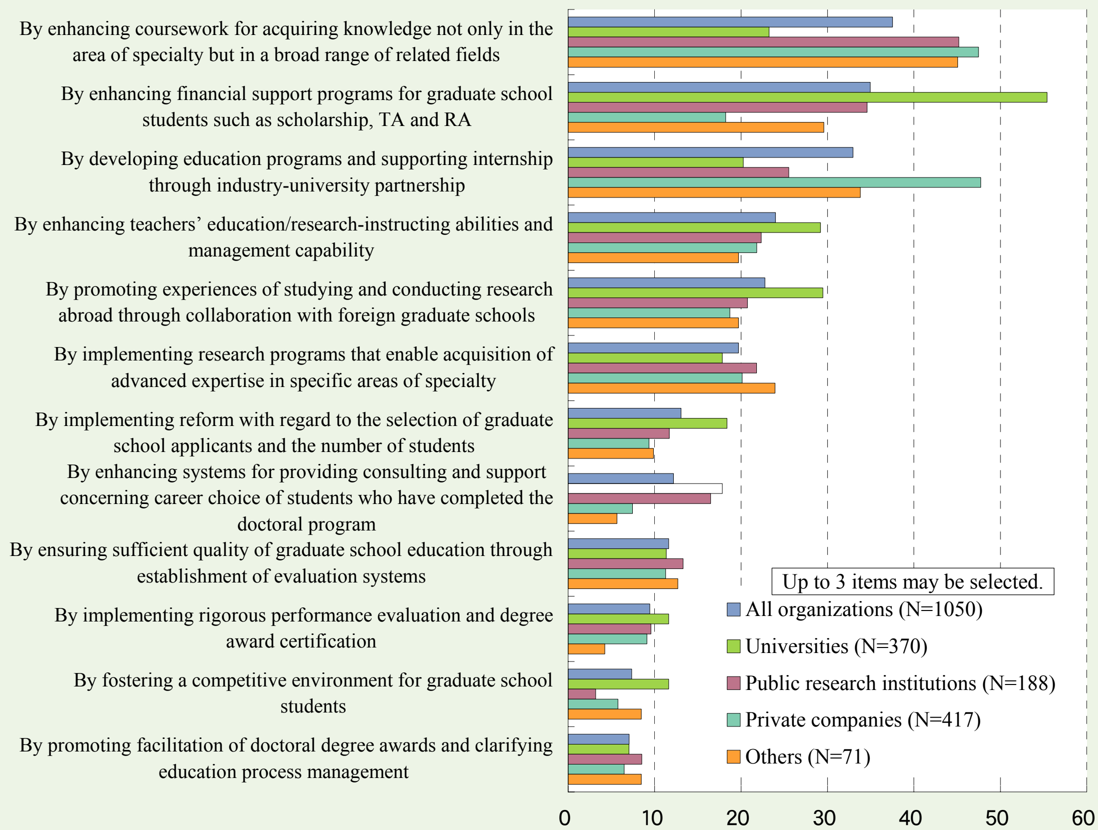
Column 7: “Enhancing Science and Mathematics Education for Next-Generation” (Science Education Assistant Allocation Project)

## (2) Drastic enhancement of graduate education

MEXT conducted a survey on researchers working at companies, universities, public research organizations, etc. as to what kind of researchers are needed at the type of organization they belong to and how they view the current status of graduate school education. Regarding attributes and capabilities necessary for researchers, “expertise in a specialized area” was selected as the first priority by the most respondents, at all types of organization. The survey indicated that the second most important element required for researchers is “creativity” at universities, “inquiring spirit” at public research organizations and “problem-solving ability” at private companies.

With regard to the question about how graduate school education should be enhanced in order to foster the kind of researchers required at the type of organization to which the respondent belongs, the most common response, across all types of organizations, was the need for “enhancing coursework for acquiring knowledge not only in the area of specialty but in a broad range of related fields.” The ratio of respondents citing this was particularly high at public research organizations and private companies (Figure 17).

■ **Figure 17 "How do your organizations want graduate school education to be enhanced in order to foster researchers?"**




Note: "N" indicates the number of respondents.
Source: "Survey of the State of Japan's Research Activities (FY2006) " by MEXT

### (Establishment of education and research centers with international acclaim)

Based on the results of the 21st COE Program mentioned above, MEXT plans to introduce the "Global COE Program," which, while retaining the basic concept of the 21st COE Program, seeks to further develop research centers by providing targeted support. This program will provide funding support for establishing education and research centers that perform at the apex of global excellence to elevate the international competitiveness of Japanese universities. The program will strengthen and enhance the education and research functions of graduate schools, to foster highly creative young researchers who will go on to become world leaders in their respective fields through experiencing and practicing research of the highest world standard.

### (Support Program for Improving Graduate Education)

MEXT intends to implement the "Support Program for Improving Graduate School Education," a reform program for doctoral programs and master's degree programs that develop advanced human resources capable of making contributions to various sectors of society by providing targeted support to excellent education initiatives being carried out in an organized and systematic manner.

## (3) Securing excellent science and technology-related human resources

It is an urgent task for countries around the world to secure an abundance of excellent human resources, and the adoption of measures for securing excellent resources has become an international trend in recent years, and programs to invite top-level researchers are increasing.

As it is important for Japan to establish bases for securing excellent human resources, MEXT is implementing the World Premier International Research Center (WPI) Initiative, while the Cabinet Office is promoting a plan to establish a world-top-class natural science graduate school open to the world in Okinawa Prefecture as part of efforts to promote the development of the prefecture.

### (World Premier International Research Center Initiative)

As a first step toward raising the standard of science and technology in Japan and consistently spurring innovations, which should serve as the engine of future development of the country, it is necessary to enhance the country's basic R&D function and international competitiveness. To this end, MEXT intends to start in fiscal 2007 the World Premier International Research Center Initiative. This program aims to establish centers with "global visibility" that will attract top-level researchers from around the world by cultivating a research environment that meets the global standard through measures such as: extending invitations to top-level researchers from within and outside Japan, introducing a strong management system and performance-based remuneration system, adopting English as the working language and providing vigorous support; and by promoting collaboration with other universities and institutions.

### (Plan to establish the Okinawa Institute of Science and Technology)

This plan aims to establish an open-to-the world, world-leading natural science graduate school in Okinawa Prefecture with a view to making contributions to global development of science and technology and developing the prefecture as the leading-edge knowledge cluster of the Asia-Pacific region. Foreign researchers have already been invited to the Okinawa Institute of Science and Technology (led by President Sydney Brenner, Nobel Prize laureate in physiology or medicine 2002), which is the implementing agency of the plan, and seminars and conferences are held there in English.

Column 8: "Examples of World Leading Research Centers"

- Carnegie Mellon University's Robotics Institute
- The University of Arizona's College of Optical Sciences

# Chapter 2 Toward Future Promotion of Science and Technology

## 1 Overview

According to the “2006 Report on the Survey of Research and Development”, compiled by the Ministry of Internal Affairs and Communications’ Statistics Bureau, R&D expenditures funded by the government in Japan totaled approximately 3,389.6 billion yen and those by the private sector in the country totaled approximately 14,397.4 billion yen in fiscal 2005. These figures mean that each Japanese citizen pays about 30,000 yen per year through the government for R&D expenditures while private companies, etc. together spend about four times as much on R&D.

This report also shows that the number of people engaged in research-related jobs totaled approximately 1.04 million, accounting for 0.8% of Japan’s total population, and about 820,000 of them, or about 0.6% of the total population, were researchers.

## 2 Lessons to be learned from the past

### (1) To surpass boundaries of industry, academia and government

The contributions of science to society represent a dynamic process that involves interaction between the two. In Section 2, Chapter 1, we showed that a variety of modern technologies have derived from quantum mechanics and high energy physics, both of which appeared to be fields of pure basic science and that the evolution of technology, for its part, has contributed to the advance of basic research. As shown in Section 3, Chapter 1, in many cases, benefits of science and technology are fed back to society over a long period of time and through a variety of processes, and they should therefore be judged from a long-term perspective.

It is becoming increasingly important for researchers engaged in the development of advanced technologies to broaden and deepen their understanding with regard to basic research. This, coupled with a rise in the number of researchers at private companies, increases the importance of education and research at universities and graduate schools. Therefore, mutual exchange between private companies and universities should be promoted in an effective manner.

### (2) To surpass various fields

The essence of science lies in questioning and seeking to resolve unknowns, regardless of whether they concern basic research or practical applications. Knowledge and activity in various fields of science and technology are not developing independently of one another but they form a dynamic system as they interact with one another in a complex manner.

Communicating with other people in an open manner without being locked up in the area of specialty broadens the perspective of researchers and brings a fresh breeze of ideas, and it is particularly important to enable young researchers whose thinking is not constrained by conventional values to play an active role.

### (3) To surpass organizational boundaries

Research organizations, particularly those engaged in basic research, need to ensure the freedom of research that enables researchers to fully exercise their capabilities. In order to enable talented researchers with a variety of backgrounds to inspire one another, it is important to facilitate exchange of information among various organizations, employ researchers in a fair manner, irrespective of whether they are alumni members or not, and from a global perspective and make efforts to increase the mobility of human resources.

### (4) To surpass the boundaries of age and gender

Young researchers play a significant role in the advance of science and technology. As well, promoting the activity of female researchers, whose ratio remains conspicuously low in Japan will be very significant for the future development of science and technology in the country. In addition to promoting the implementation of systematic education and the independence of young researchers under the Support Program for Improving Graduate School Education, it is necessary to carry out measures such as adopting a competitive funding program that attaches importance to the novelty of research plans and utilizing young researchers in screening of research programs.

### (5) To surpass national borders

Many researchers cross national borders so as to exchange opinions with foreign researchers, develop their own capabilities and find a place where they can tackle a challenging task. To attract such capable researchers, it is necessary to make intensive efforts to establish bases in Japan that will serve as a magnet for top-level researchers. In addition, as the scale of research programs expands, the need is growing for international cooperation in prompting science and technology.

### (6) To surpass the boundary between scientists and ordinary people

The promotion of science and technology has now become a huge project into which national resources are poured. Therefore, it is necessary for scientists and ordinary people to discuss issues related to science and technology and society on an equal footing so as to ensure appropriate public understanding of the benefits of science and prevent science from going out of control unexpectedly.

In order to promote science and technology, with the support of the public, as something beneficial for the future of Japan, it is increasingly important to facilitate dialogue, in as plain language as possible, between scientists and ordinary people and form a national consensus.

### (7) To surpass the boundary of conventional thinking

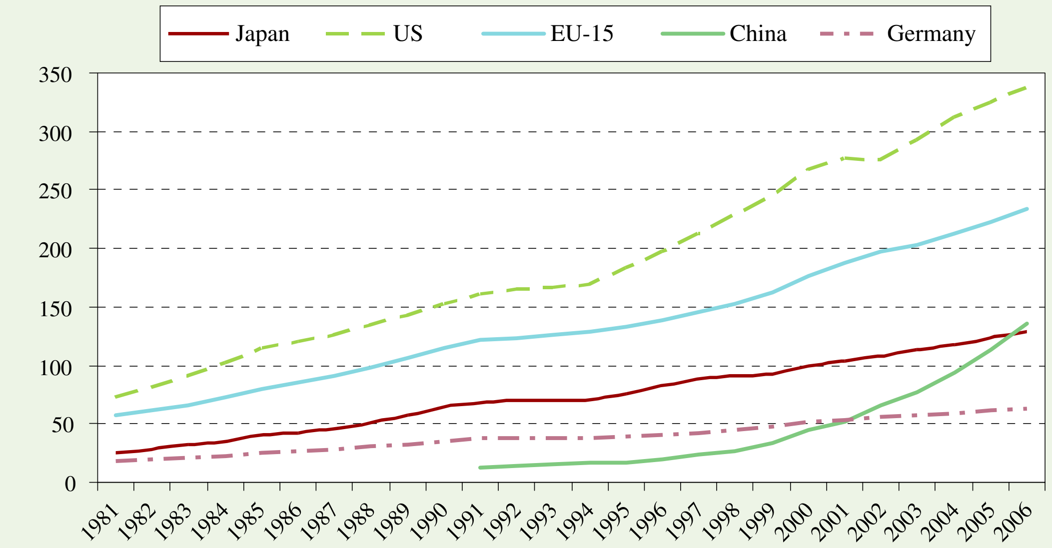
Ideas such as the Copernican theory and the theory of evolution were initially regarded as heretical but eventually came to be accepted as conventional ideas, after being verified through a variety of observation activities conducted over a long period of time. Future creative scientists willing to tackle the unresolved and unknown are sure to find the way to a solution by furthering their reasoning beyond the boundary of conventional thinking and by exercising their sound skepticism to the full.

## 3 How science and technology should be promoted in the future

### (1) Investment in science and technology

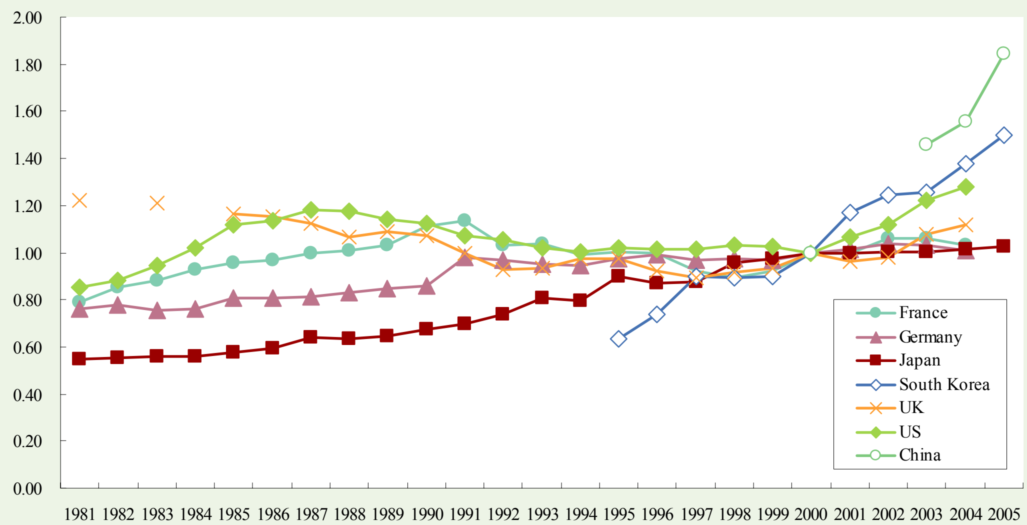
Major countries around the world are increasing their R&D expenditures as forward-looking investments. China's expenditures have shown a particularly sharp increase, and according to an estimate by the OECD, they exceeded Japan's expenditures in 2006 on a purchasing power parity basis (Figure 18). Although Japan made efforts in the past to raise government-funded R&D expenditures, such expenditures have remained almost flat in recent years, in contrast to the rapid increases in the expenditures of countries such as China and South Korea (Figure 19). Compared with the situations in other countries, the government's share of expenditures on R&D and basic research in Japan is relatively small, and public financing for higher education accounts for only 0.5% of GDP, a level about half of the figures for the United States, France and Germany and about two-thirds of the figure for the United Kingdom (Figure 20). In order to keep attractive the career path for people willing to make contributions to society by acquiring advanced knowledge in science and technology fields at graduate schools, it is necessary to make strenuous efforts to cultivate an environment that enables the implementation of sufficient education and research, reduce the financial burden on students enrolled in master's degree and doctoral programs and reform the contents and method of education so as to allow students to acquire knowledge and capabilities useful for real-life society.

## ■ Figure 18 Total domestic expenditures on R&D (unit: US$1 billion, purchasing power parity basis)



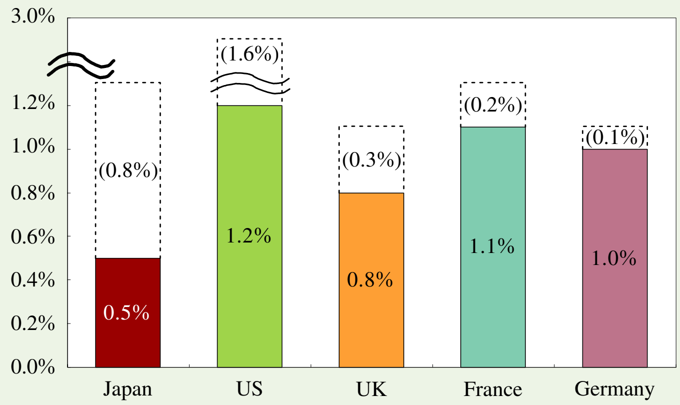

Note: Figures for 2005 and 2006 are estimates calculated based on the assumption that the growth rate of R&D expenditures in these years was the same as the average growth in 2000 to 2004.
Source: "Main Science and Technology Indicators, 2006-I" by OECD

## ■ Figure 19 Trends in government-funded real R&D expenditures in major countries with figures for FY2000 taken as the base of 1




Note:
1. Real R&D expenditures are calculated with the use of the Implicit GDP Price Indices of "Main Science and Technology Indicators by the OECD (2000=1.00).
2. Figures for 2000, the earliest year when data for all of the seven countries covered became available, are taken as the base of 1.
Source: "Report on the Survey of Research and Development" by the Statistics Bureau of the Ministry of Internal Affairs and Communications

■ **Figure 20 Public financing for higher education as a percentage of GDP**




Note: Figures in parentheses represent private-sector expenditures as a percentage of GDP.
Source: "Education at a Glance" (2006 Edition) by OECD

## (2) Selection and concentration

The Third Science and Technology Basic Plan calls for promoting strategic priority setting for government-funded R&D expenditures through selection and concentration and selects items targeted for intensive investments during the period of the plan as "strategic prioritized S&T." Moreover, projects for which "concentrated investments" are required are characterized as "Key Technologies of National Importance." Such technologies include: the "next-generation supercomputer," the "X-ray Free Electron Laser project," the "space transport system," the "earth observation and marine prospecting system," and the "fast breeder reactor (FRB) cycle technology."

Meanwhile, in order to enable individual researchers to develop original and challenging ideas, it is important to expand competitive funding while maintaining a certain level of basic expenditures.

## (3) Promoting science and technology in ways to obtain public support

The advance of science and technology has benefited mankind by bringing about long life and material welfare. Given the expected increase in affluence due to a rise in the living standards of more countries and the expected expansion of the global population, however, the level of technology as it is would be insufficient to prevent us and our offspring from being confronted with environmental constraints in the future. Under such circumstances, we face the critical decision of which sorts of science and technology we should seek to develop further: the future for us and our offspring depends on this decision. In making this decision, it is important to obtain the understanding of the taxpayers regarding the sorts of science and technology to be selected for promotion and the way of advancing them. To this end, researchers and people involved in the promotion of science and technology should make constant efforts to provide comprehensive explanations concerning their activities and advance science and technology in the right direction with the participation of ordinary people.

Column 9: "Cherishing Creativity of Individuals" (Dr. Leo Esaki)

## Chapter 1 R&D Expenditures

- Total R&D Expenditures
- R&D Expenditures by Financing and Performance
- R&D Expenditures per Researcher
- R&D Expenditures by Character of Work
- R&D Expenditures by Industry
- R&D Expenditures in Japan by Sector
- R&D Expenditures in Japan by Type

## Chapter 2 Research Personnel

- Researchers
- Personnel Engaged in R&D
- Production and Employment of Research Personnel

## Chapter 3 Trends Related to Research Performance

- Scientific Papers
- Patents
- Technology Trade
- High-tech Industries

## Chapter 4 Efforts to Develop New Science and Technology Indicators

- Efforts by the OECD
- Efforts in Japan

## Chapter 1 Development of Science and Technology Policies

■The Science and Technology Basic Plan
■The Council for Science and Technology Policy
■Administrative Structures of Science and Technology and the Budget

## Chapter 2 Strategic Priority Setting in Science and Technology

■Promotion of Basic Research
■Priority Setting in Research and Development for Policy-Oriented Subjects

## Chapter 3 Reforming the Science and Technology System

■Developing, Securing and Activating Human Resources
■Creating Scientific Development and Persistent Innovation
■Reinforcing the Foundation for Promoting Science and Technology
■Strategically Promoting International Activities

## Chapter 4 Science and Technology to Be Supported by Society and the Public