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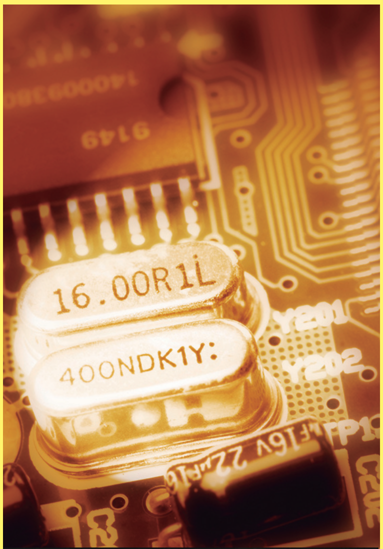

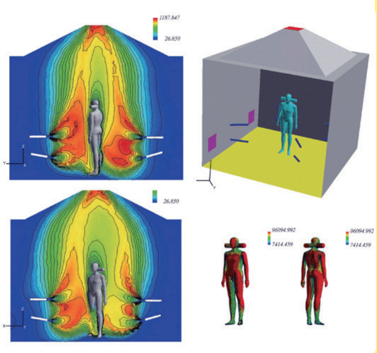

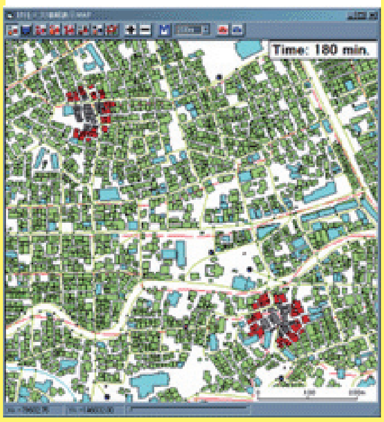

Foreword

This is the latest issue of "Science and Technology Trends — Quarterly Review".

National Institute of Science and Technology Policy (NISTEP) established Science and Technology Foresight Center (STFC) in January 2001 to deepen analysis with inputting state-of-the-art science and technology trends. The mission of the center is to support national science and technology policy by providing policy makers with timely and comprehensive knowledge of important science and technology in Japan and in the world.

STFC has conducted regular surveys with support of around 2000 experts in the industrial, academic and public sectors who provide us with their information and opinions through STFC's expert network system. STFC has been publishing "Science and Technology Trends" (Japanese version) every month since April 2001. The first part of this monthly report introduces the latest topics in life science, ICT, environment, nanotechnology, materials science etc. that are collected through the expert network. The second part carries insight analysis by STFC researchers, which covers not only technological trends in specific areas but also other issues including government R&D budget and foreign countries' S&T policy. STFC also conducts foresight surveys periodically.

This quarterly review is the English version of insight analysis derived from recent three issues of "Science and Technology Trends" written in Japanese, and will be published every three month in principle. You can also see them on the NISTEP website.

We hope this could be useful to you and appreciate your comments and advices.

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NISTEP has moved to a new office

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Executive Summary

Life Sciences

1 New Japanese Graduate School Programs for Human Resources Development in Clinical Research

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Progress in clinical research is expected to result in numerous new drugs and therapeutic methods which will be useful in maintaining and improving the health of the Japanese people. However, in Japan, the systems for implementing clinical research and translating the results of basic research into clinical applications are generally considered not enough. The failure to adequately secure high quality human resources to carry out clinical research has been pointed out as a root cause of these various problems.

First, in order to clarify the type of the clinical researchers required by Japan, the descriptions of policies and recommendations for promoting clinical research published from 2006 to 2007 were analyzed. As a result, it was found that four types of clinical researchers are required, these being "researchers who have strong ability in both basic research and clinical research," "researchers oriented toward cooperation/integration with other fields," "specialists in clinical research," and "researchers who play a leading role in clinical trials."

Because clinical research centers on research carried out through medical treatment, it is desirable that clinical researchers possess the fundamental knowledge and skills of physicians and also have received training as researchers. However, the timing when a physicians can begin a career as a graduate school researcher is delayed in comparison with researchers in other fields, as physicians must complete 6 years of medical school education to acquire the requisite basic knowledge and skills, followed by a legally-required 2-year New Postgraduate Medical Training and an additional 3-5 year residency as training for specialists. Thus, in training clinical researchers, improvement of the graduate school education system considering physicians' career paths is necessary. To achieve this, the establishment of a system in which graduate education acts as an incentive for physicians and a program supporting the formation of physicians' careers is desirable.

Several universities have already begun programs for training human resources in clinical research. The "Initiatives for Attractive Education in Graduate Schools" program (Ministry of Education, Culture, Sports, Science and Technology (MEXT), Higher Education Bureau, University Promotion Division and Japan Society for the Promotion of Science) supports human resources training programs in graduate schools. This also includes training of human resources in the field of clinical research. The "Interdisciplinary Systematic Medical Education Career Path Formation" program at Kyoto University is a program for training human resources, which combines specialized knowledge in a wide range of medical fields and deep expertise, and is therefore expected to train researchers who are strong in both basic research and clinical. The "Medical-Engineering Integrated Practical Education Program" at Yamaguchi University is a new human resources training program for education/research which integrates medicine and engineering, with its focus narrowed to developmental research on advanced medical equipment and materials. "Reform of Graduate School Education for Activation of Clinical

Research" at Kyushu University is a program for training specialists in clinical research considering their career path as physicians, and is expected to become a model program for promoting postgraduate education of physicians in the future. The "Clinical Trial Leader Training Program" at Yokohama City University is the only program in Japan with an actual course focused on training of clinical trial physicians. An increasing number of graduate schools are expected to create courses of this type in the future.

Promotion of this type of postgraduate human resources training program at the national level is important for securing the human resources with a high level of expertise that Japan will require in the future. From this viewpoint, it is necessary to expand programs which support young researchers in coordination with these human resources training programs, for example, by providing research funding and economic support for basic everyday needs to individuals participating in these programs.

(Original Japanese version: published in August 2007)

Information and Communication Technologies

2 Trends and Issues in Research on Context Awareness Technologies for a Ubiquitous Network Society

p.26

The coming years may see the creation of the environment referred to as a "ubiquitous network society" or "ubiquitous information society," in which an inconspicuous system of computers provides diverse types of information in various everyday surroundings. Although the technologies for realizing this environment span a diverse range, in particular, the function of "use of ICT (information and communication technology) without user's awareness" is realized by the field of technology called "context awareness."

With this technology, information is obtained from numerous sensors arranged in the home, workplace, city, and other spaces where people engage in everyday activities. This information is used determine the details of the user's actions and the constantly-changing condition of the environment, in other words, "context." The system then performs the service of providing useful information to the user at appropriate times. For this, however, the user's actions must be recorded in detail by computers or third parties. Consequently, there is also a danger that personal information about the individual may be processed "without the user's awareness."

The challenge in this area of technology is to satisfy both protection of privacy and design of good applications.

Because the aim of this technology is to create a better environment, a major premise is that monitoring of personal actions and the environment in order to create a better ubiquitous network environment should be performed with benevolent intentions. Needless to say, a system based only on this premise will be extremely vulnerable to unauthorized use with malevolent intentions. This means that innovation aimed at minimizing leaks of personal information is necessary. Moreover, even assuming that an adequate environment for handling personal information can be created, good service will not necessarily be available in the initial stage. There are cases in which this is only achieved after a technology has been popularized and is in actual operation. In other words, the chicken-or-egg paradox applies here, in that evolution of the technology and maturation of the related social system must proceed together.

Where the context distribution infrastructure is concerned, rapid creation of common specifications that are acceptable to most researchers is essential. Beyond this, it will be necessary to create conditions for refining the content of services, under which diverse applications are selected or discarded through a trial-and-error process and only desirable applications remain. Moreover, while carrying out R&D on individual element technologies, it is necessary to have a clear vision of the kind of society which we wish to construct, and to develop system design concepts based on that vision.

(Original Japanese version: published in August 2007)

3 IT-Based Industrial Development in India and Trends in Human Resources Development with the Aim of Realizing a Knowledge-Based Society

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India, which is one of the BRICs countries, has achieved rapid economic expansion as a result of liberalization of its economy and development of IT-related industries, giving the country a rapidly increasing presence in the global economy. India is expected to become the world's third largest economy by 2050. Unlike Japan, where the declining birthrate is becoming a major problem, India's young generation under the age of 25 accounts for 50% of the total population of 1.1 billion. In addition to this abundant workforce, India's competitive edge can also be attributed to the fact that it is the world's largest democratic country, its people have high level of English proficiency, and labor wages are relatively low. However, the most important factor may be India's social system, which continuously produces human resources with high potential.

India's progress has been supported by IT industries, centering on software. The contribution of IT in 2007 is estimated at 5.4% of GDP. India has grown to become a major international power in the software business with a global share of 60%. India's next targeted market is the biotechnology industry. India has started to focus national support on bioinformatics, which is highly compatible with the IT industry and forms part of the technological infrastructure for biotechnology. Many projects related to bioinformatics are now in progress with new research facilities. India is also making efforts to improve its supercomputing capabilities to support bioinformatics. In addition to applications in life science, exemplified by drug discovery, diagnostics, and therapy, these projects have large potential in a wide range of businesses, extending to biofuels, agriculture, and similar fields.

Industrial progress of this type is backed by human resources. However, even India, with the second largest population in the world, is facing difficulties in securing the necessary human resources to support its current extremely high level of economic growth. Shortages of human resources will of course be detrimental to sustained economic growth, and will also become a serious barrier to improving international competitiveness. To overcome this situation, India is working very hard to educate its people to fill the gap between the human resources produced by academia and the needs of industry by enhancing its higher education system.

India has a strong sense of crisis with regard to the shortage of human resources, and is therefore actively educating human resources and moving to secure human resources internationally. The reason for this is presumably that India is targeting development as a knowledge-based society and considers human resources to be the key driving force for the coming new age. What India desires to achieve is nothing less than a transformation of its economic structure from conventional outsourcing to knowledge-industry outsourcing based on its highly capable human resources, and to develop as a knowledge-based society. In addition to its abundant young population, India is now making steady progress in enhancing its higher education system. Nevertheless, even India is making global efforts to secure excellent human resources. Japan should give careful attention to developments in this regard.

(Original Japanese version: published in September 2007)

Nanotechnology and Materials

4 Research and Development Trends in Solid Oxide Fuel Cell Materials

— From the Viewpoint of Electrolyte-Related R&D as Key—

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Among the various fuel cell technologies, solid oxide fuel cells (SOFCs) offer a number of important advantages. In addition to high operating efficiency and excellent long-term performance stability, the electrochemical reaction of fuel and air can be achieved without noble metal catalysts, and a diverse range of fuels can be used. As a result, SOFCs have been an object of intensive R&D (research and development) in recent years. Confirmation tests of the SOFCs system are currently in progress, and the efforts now focus on maintaining long-term generating performance, reducing costs, and achieving high reliability, as these are critical issues for practical application. The SOFCs which are currently in the confirmation test process are mainly medium- and large-scale systems with high operating temperatures in the range of 750°C-1,000°C. Commercial introduction of these systems is planned after long-term generating performance and reliability are confirmed. However, it now appears that more time than originally expected will be needed to solve the above-mentioned problems. In addition, the costs of these SOFCs systems are still not competitive with other generating systems.

In order to develop the high temperature systems now in the confirmation test stage to a stage where commercialization is possible, it will be necessary, in R&D on maintaining system generating performance, to elucidate the mechanism responsible for deterioration of the performance of cell component materials, beginning with the electrolyte. This will require an investigation of the mechanism of ion and electron conduction reaching back to the nano region of the material, as well as R&D related to analytical/characterization technologies to support this basic research. Likewise, in securing reliability, it is desirable to establish techniques that enable high accuracy computer simulation of damage and deterioration, and to carry out R&D aimed at improving reliability efficiently using those techniques together with experimental analyses of the deteriorating mechanism of component materials. In order to reduce the costs of systems, it is necessary to adopt low-cost component materials, including the electrolyte, in cells and stacks, and to establish an appropriate mass production process. In particular, because the microscopic/macroscopic structure of component materials controls the electrochemical and mechanical properties of the fuel cell, it is quite important to mass produce component materials with the same micro/macro structures as in small-scale prototypes.

On the other hand, recent R&D on SOFCs electrolytes has included an active search for materials with high oxygen ionic conductivity0 in the medium temperature (500°C-750°C) and low temperature (<500°C) ranges, such as scandia-stabilized zirconia and lanthanum gallate, as alternatives to yttria-stabilized zirconia (YSZ) and others used in high temperature operation, based on the expectation that the three problems mentioned above can be solved simultaneously by reducing the operating temperature. Although R&D on systems using these new electrolytes is still in the germinal stage, systems of this type have the potential to solve, at a single stroke, all of the problems confronting high temperature systems.

Given the condition of R&D described above, if it is judged difficult to solve the problems involved in commercializing high temperature systems, one option is a decisive shift in R&D to low temperature systems. In view of the remarkable progress on nanotechnology in recent years, this search for new electrolytes should be carried out from the directions of both theoretical analyses and experimental verification using nano-level computer simulation and experimental techniques. In any case, it is important to select materials with a view to mass production processes for cells and stacks, envisioning the practical SOFCs systems of the future from the material search stage.

(Original Japanese version: published in July 2007)

Monodzukuri (Manufacturing) technology

5 Proposals for Research and Development on Monodzukuri (Manufacturing) Measurement Supporting the Competitiveness of Japanese Manufacturing Industries

p.71

Japan's manufacturing industries enjoy a position of international superiority but continue to be exposed to fierce competition from many countries, not limited to the industrial nations of Europe and North America. To maintain and strengthen international competitiveness in the future, Japanese manufacturing industries must create products which have an impact on world markets, achieve innovation in design and manufacturing processes, and dramatically improve product reliability through science-based manufacturing. An essential requirements for science-based manufacturing is "monodzukuri measurement," in which physical quantities related to product performance and manufacturing processes are digitized and the results of data analysis are explained in scientific and technical terms. (Note: In this article, "monodzukuri" refers to unique Japanese manufacturing methods.) Because monodzukuri measurement requires an accumulation of technologies extending over many years and technologies suited to specific products and manufacturing sites, it is not easily introduced from outside by simple financial investment. Japan's international superiority in monodzukuri measurement technology supports the strength of the country's manufacturing industries. In the Third Science & Technology Basic Plan, "Science-based manufacturing 'visualization' technology that further advances unique Japanese-style monodzukuri technology," in which monodzukuri measurement is one key element, was selected as a "Strategically prioritized S&T" in the Monodzukuri Technology field.

The requirements for research and development on monodzukuri measurement may be summarized as follows.

(1) In research and development, treatment of monodzukuri as a composite technology encompassing measurement, design, the manufacturing process, and measurement is indispensable.

Because monodzukuri measurement is closely related to product functions and quality, R&D on monodzukuri measurement is not possible if measurement is treated as an independent subject. Important measurement conditions, including measurement objects and methods and the types of data handled are derived from the design specification, and analyses of measured results must be based on design/manufacturing process technologies.

(2) As a national project, monodzukuri measurement should be discussed based on an overview of the issue as a whole.

In monodzukuri measurement, it is frequently impossible to solve problems simply by improving the performance of instrumentation equipment. In national projects involving monodzukuri measurement, first, research must treat the issues related to monodzukuri measurement as a whole. As part of this process, the specifications required in measuring devices must be clarified, and R&D on measuring devices must be based on the required specifications discovered as a result.

(3) In industry-academia-government collaboration, it is necessary to strengthen efforts related to international standardization in the field of measurement and the establishment of traceability.

In order to guarantee product quality in a global manufacturing economy environment, technology that supports international traceability to secure international consistency in measurement standards are necessary. It is also necessary to strengthen cooperation in efforts by industry, academia, and government, which are generally independent. For Japan's manufacturing industries to promote a further international division of labor, Japan must actively take the initiative in international standardization in the field of measurement.

(Original Japanese version: published in July 2007)

Social Infrastructure

6 Science and Technology Trends relating to Fire and Disaster Management

— Toward Innovations of Fire and Disaster Management —

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Japan was formerly considered a safe country. However, deterioration of facilities due to aging and unsafe conditions are progressing in many aspects of the society, as evidenced by the rapidly increasing trend in the annual death toll due to residential fires in recent years. In addition, new factors that threaten the safety of the society and the citizens' sense of safety and security are emerging, such as the new overcrowded urban spaces being created by urban development. "Achieving a Safe Society in which People Can Live with a Sense of Safety and Security" is one of the main objectives of the Third Science and Technology Basic Plan, and science and technology in the field of fire and disaster management contribute toward achieving that objective. Some of the research and development areas in science and technology in the field of fire and disaster management have been designated as priority research areas under the research area-specific promotion strategy. When utilizing outcomes of science and technology, it is necessary to do so both from the standpoint of disaster prevention, including identification of potential hazards and establishment of safety requirements (including the incorporation of S&T outcomes in legal requirements), and from the standpoint of coping with disasters after they occur, including upgrading of firefighting equipment. So far, efforts to utilize outcomes of science and technology in developing legal requirements have borne some fruit, but the utilization of S&T outcomes in coping with disasters after they occur, such as the utilization of outcomes in improving actual firefighting activities, has not necessarily been pursued sufficiently. Effective use of limited research resources requires the identification of important research areas and intensive allocation of research resources to them. In addition, policies and measures that allow the fruits of research to be made available to the society in a more practical manner are need now more than ever.

Currently, there are a total of 9 local government firefighting organizations in Japan that have a fire and disaster management-related research and development department. The total R&D budget for these 9 fire and disaster management-related research and development departments is approximately €100 million. These R&D organizations conduct field-oriented technological development and applied research, including research to improve and upgrade firefighting equipment and materials, as well as investigations, analyses and tests to identify the causes of fires. At the national level, a Firefighting Technology Policy Office was established in the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications in April 2006, and the Fire and Disaster Management Agency and its National Research Institute of Fire and Disaster are conducting joint industry-government-academia research and development to address the common challenges for all prefectures of Japan, including the development of equipment for emergency firefighting assistance teams, development of an information system for coping with large-scale natural disasters including earthquakes, and research to establish methods of predicting the spread of fires in overcrowded urban spaces. “Exit-oriented” research and development activities (R&D oriented toward translation of research outcomes into practical applications) at the Agency and Institute include collaborative attempts by industry, academia, and various government agencies and organizations to (1) develop nanotechnology-based firefighting clothing, (2) introduce and deploy technologies that allow helicopters and communications satellites to directly communicate with each other, and (3) deploy reconnaissance and assistance robots.

To enable more effective future use of R&D outcomes in fire and disaster management at the field level, it is important to consider a “mechanism that works taking into consideration how the R&D outcomes will be valued by the procurement departments of users.” The major innovation-inhibiting factors unique to science and technology in the field of fire and disaster management include the small scale of the market (the share of equipment-related expenditures as a percentage of the total national firefighting budget is 10% or less) and the fact that the nearly 800 fire headquarters located throughout Japan procure equipment and materials independently. To solve these problems, it is considered important that the national and local governments work in close cooperation and coordination. For example, the development of standard specifications and introduction of joint procurement systems under the leadership of the national government can be effective in solving these problems. In addition, it is considered that, in order to develop R&D outcomes into innovations for the society, science and technology coordinators who can objectively understand, evaluate, and explain the outcomes of research and development are essential, and that developing and implementing policies and measures for nurturing such coordinators is an important task for the future.

(Original Japanese version: published in September 2007)

Frontier

7 Overseas Trends in the Development of Human Occupied Deep Submersibles and a Proposal for Japan's Way to Take

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Human occupied submersibles now make it possible to explore and conduct research on 99% of the earth's ocean floor. Acting deep-submersible human occupied vehicles (HOVs) include Japan's Shinkai 6500, which is operated by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and has the maximum depth of 6500m, the Alvin (maximum depth: 4500m) of Woods Hole Oceanographic Institution in the United States, the Nautile (6000m) of the French Research Institute for Exploitation of the Sea (IFREMER), and Russia's Mir I & Ⅱ (6000m). Since her first dive in June 1990, Japan's Shinkai 6500 has made a variety of achievements, taking advantage of the world's deepest operating range, and completed its 1000th dive in March 2007.

In the United States, the Alvin has completed more than 4000 dives since her launch in 1964, and the construction of next-generation new HOV with a maximum depth of 6500m started October 2005. Important technologies including the buoyancy material, pressure hull, power supply, buoyancy control system and others, are being greatly improved assuming a 2.5 hour of descending time to 6500m. Operation for scientific research is scheduled to begin 2010. Although the development of this vehicle was the subject of considerable controversy with another group that favored the development of an unoccupied vehicle, a compromise was reached based on the fact that both occupied and unoccupied vehicles are necessary, and the development was approved. China has now constructing a 7000m class HOV which will have the world's deepest operating range. This is considered to reflect China's determination to seize the initiative in military affairs and in securing seafloor resources. While China is supposed to have few key technologies such as the technologies required in deep-submersible HOVs, the pressure hull and buoyancy materials were provided from forign countries, and China was said to have developed the other technologies aiming at completion in 2008. How China will establish 7000m class safety/reliability technologies is a matter of considerable future interest.

The aims of research using HOV include elucidation of the history of the planet and evolution of living organisms, exploitation/preservation of deep-sea life, and elucidation of thermal and materials cycles, among others. In the future, Japan should keep its initiatives in deep sea science and technology. To this end, we must provide scientists with advanced research tools and maintain and develop technologies related to deep-submersible HOVs. Almost twenty years have now passed since Japan built the Shinkai 6500, and while partial improvements have been made in its functions, we are now in a point to study a next-generation HOV incorporating various new technologies that meet scientists' requirements. As one of the countries which have led the world in deep-sea underwater/ocean floor research up to the present, Japan should develop a new 3rd generation HOV that enables rapid diving/surfacing, mid-level dives at arbitrary depths, and extended dives, including a system that makes it possible to conduct safe and efficient research in collaboration with unoccupied vehicles.

(Original Japanese version: published in September 2007)

1

New Japanese Graduate School Programs for Human Resources Development in Clinical Research

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1 Introduction

Clinical research*1 has been defined as "medical research for the purposes of improving preventive methods, diagnostic methods, and therapeutic methods for disease in medical treatment, understanding the causes and pathology of diseases, and improving the quality of life of patients, with human beings as its object (including research on materials and data of human origin which can designate individuals)."[1]

In short, however, clinical research is "research on human beings." As such, it includes the "clinical tests"*2 used to investigate the safety and efficacy of candidate substances and practices in the development of new drugs and therapeutic methods. In this, clinical tests which are carried out in order to obtain approval for the manufacture and sale of pharmaceuticals, etc. from the Ministry of Health, Labour and Welfare are called "clinical trials."*3

The creation of numerous new drugs and therapeutic methods through progress in clinical research has large direct benefits in maintaining and improving the health of Japanese citizens. In the coming years, Japanese elderly ratio (percentage of population 65 years of age or older to the total population) will increase, and will eventually exceed the level defining a "ultra-aged" or "elderly-dominated" society (terms vary; but refer to an elderly ratio of 21% or higher). This means that activation of clinical research, including clinical trials and clinical tests, is an extremely important challenge for Japan.

At present, Japan is one of the small number of nations in the world with the capability to develop new drugs by own country. In 2004, pharmaceutical products developed in Japan accounted for 13 of the world's top 100 pharmaceuticals in terms of sales value, ranking 3rd behind the United States, which ranked 1st with 39 products, and the 2nd-ranking United Kingdom, with 14.[2] On the other hand, the percentage of Japanese papers published in leading journals on clinical research was lower than the percentage carried in journals such as "Nature" and "Science," which publish high quality papers on basic research in the life sciences.[3] These conditions can be considered to reflect the basic difficulty of clinical research in Japan, which can be attributed to the inadequate clinical research system in this country, and to the lack of a "translational system" for translating high quality basic research in the life sciences into clinical research. As another problem, it has also been pointed out that the system for reviews and clinical trials of pharmaceuticals is inadequate in comparison with those in the United States and Europe.

The common, fundamental issue for solving these various problems and activating clinical research in Japan is considered to be the training of clinical researchers. The main organizations engaged in clinical research are university graduate schools, and the persons principally involved are physicians. Therefore, this paper will examine several interesting new training programs for human resources in the field of clinical research currently in progress in graduate school medical research departments, which have been developed for graduates from medical schools. In particular, the distinctive features of these programs are identified, the content of the programs is discussed, and future policies for training clinical researchers are discussed.

2 Distinctive features of clinical research

Because its object of clinical research is human beings and materials of human origin, clinical research must consider safety and bioethics. In carrying out such research, it is necessary to follow various guidelines, as shown in Table 1.

Furthermore, the single term "clinical research" encompasses research for a variety of different purposes, including "clinical trials" for approval of pharmaceuticals and the like, "clinical tests" other than clinical trials, which are conducted, for example, to improve standard treatment methods, and "translational research (TR),"*4 which is a type of research bridging basic research and clinical research with the aim of developing new medical technologies efficiently.[4] (See Table 2.) For this reason, the necessary guidelines will differ, depending on the type of clinical research. Concretely, detailed standards for clinical trials are spelled out in Japan's Pharmaceutical Affairs Law and the Ordinance on Good Clinical Practice (GCP; ordinance concerning standards for implementation of clinical trial of pharmaceuticals).

In addition, when considering human resources for activation of clinical research, appropriate human resource, development policies will differ depending on the type of clinical research. For example, the training policies for clinical research oriented "basic research" such as TR, are different from those for research which must be carried out in accordance with a process prescribed by a system, as in as clinical trials.

Table 1 : Representative laws, guidelines, etc. for clinical research

Law, guideline, etc.	Date of adoption or enforcement	Body responsible for adoption, enforcement, etc.
Declaration of Helsinki (Ethical principles for medical research involving human experimentation)	June 1964	World Medical Association (WMA)
Ethical Guidelines for Clinical Research	July 2003	Ministry of Health, Labour and Welfare (MHLW)
Guidelines for Clinical Research on Gene Therapy	March 2002	Ministry of Education, Culture, Sports, Science and Technology (MEXT), MHLW
Ethical Guidelines for Research on Human Genome/Gene Analysis	March 2001	MEXT, MHLW, Ministry of Economy, Trade and Industry (METI)
Ethical Guidelines for Epidemiological Research	June 2002	MEXT, MHLW
Ideal Form of Research and Development using Human Tissue Obtained in Medical Operations, Etc.	December 1998	Health Sciences Council (Report)
Guidelines for Establishment and Use of Human Embryonic Stem (ES) Cells	2001	MEXT (Notification)
Act concerning Protection of Personal Information	May 2003	
Common Ethical Review Guidelines for Translational Research	January 2004	The University of Tokyo, Institute of Medical Science, Research Hospital, Advanced Clinical Research Institute; Nagoya University Hospital, Center for Regenerative Medicine; Kyoto University Hospital, Translational Research Center; Osaka University Hospital, Medical Center for Translational Research; Kyushu University Hospital, Department of Advanced Medical Engineering Therapeutics/Clinical Research Center; Foundation for Biomedical Research and Innovation, Institute of Biomedical Research and Innovation (IBMR)/Translational Research Informatics Center (TRI)
Guideline for Good Clinical Practice (Ministerial Ordinance; GCP Ordinance)	March 1997	MHLW *Related law: Pharmaceutical Affairs Law

Prepared by the STFC

Table 2 : Comparison of translational research (TR), Physician-led clinical tests, and clinical trials

	TR	Physician-led clinical test	Clinical trial
Purpose	Efficient development of new medical technology	Innovation or improvement of standard therapeutic method	Application/approval of new medical technology
No. of subjects	Small	Small to Large	Small to Large
Leader	Researcher or Physician	Physician	Private company or Physician
Source of research funds	National government, private company, venture capital, researcher	Private company, national government, researcher	Private company
Supplier of reagents/test product	Researcher, private company, national government	Private company	Private company

From Reference [4]

3 Types of clinical researchers required in the future

Various recommendations and policies for science and technology policy related to the promotion of clinical research were announced from 2006 to 2007. Here, four representative sets of recommendations will be discussed. (See section 3-1, (a) to (d).) These four sets of recommendations are divided into "Recommendations mainly concerning clinical research" and "Recommendations mainly concerning clinical trials." Types of the clinical researchers who will be required in the future of Japan will become apparent from the outline of these respective items and description of human resources for clinical research.

3-1 Recent recommendations and policies

(1) Recommendations mainly concerning promotion of clinical research

(a) In the field of Life Sciences in Promotional Strategies by Field (Cabinet Resolution of March 28, 2006)[5] in the Third Science and Technology Basic Plan laid out by the Japanese Cabinet's Council for Science and Technology Policy (CSTP), "Translational research to clinical research and clinical trials" was selected as a Strategically prioritized S&T for investment on a priority basis during the period of the 3rd Plan (FY2006-FY2010).

The content of this research and development is shown below.

- Translational research, clinical research, and clinical trials contributing to the use of research results and innovative diagnostic and therapeutic methods aiming at early practical application, and to the use of pharmaceuticals and others which are generally used in other foreign countries but have not been approved in Japan.
- Improvement of the support system for clinical research and translational research.
- Training and securing human resources contributing to promotion of clinical research (including human resources with expertise in epidemiology and biostatistics).
- Research and development promoting practical application of results, such as higher efficiency in the drug discovery process.

As a policy for the Life Sciences field, the plan advocates "creation of a system for promoting clinical research," and mentions that, "in order to return the results of research to the Japanese people in the form of new pharmaceutical products, medical equipment, etc., it is important to promote four efforts, namely, creating and strengthening the support system, securing and training clinical researchers and clinical research support personnel, creation of an environment for promoting research and examination and approval, and participation of the Japanese people."

(b) In December 2006, the Center for Research and Development Strategy (CRDS) of the Japan Science and Technology Agency (JST) published "Strategy Recommendations for Clinical Research —Aiming at Fundamental Reform of the Clinical Research System in Japan."[6] This was followed by "Promotion of Integrative Celerity Research (ICR)—

Innovation in Health and Medical Care" in March 2007.[7]

It is assumed that "a wealth of knowledge on the life sciences is being accumulated as a result of substantial investment in basic research in the life sciences, but because the system for implementing clinical research is weak, and there are also problems in the organizations responsible for review and approval (of pharmaceuticals), it is difficult to translate the results of basic research into practical applications quickly." Therefore, fundamental reform of the clinical research system and the review and approval system is recommended.

Concrete recommendations include "Establishment of Clinical Research Basic Law," which positions clinical research as one of the most critical items for national policy, "Creation of centers for clinical research, establishment of composite clinical research bodies, and formation of a network" to enable researchers in different fields to routinely create cooperative systems by placing the functions of basic research, clinical research, and advanced medical research and development in one location, and "Measures for promoting Integrative Celerity Research (ICR): Securing funds, systemic reform, and training of human resources."

(2) Recommendations mainly concerning activation of clinical trials

(c) In the area of clinical research in Japan, including clinical trials, the Expert Panel on Basic Policy in the Cabinet's above-mentioned Council for Science and Technology Policy positioned "elimination of systemic and administrative obstacles to smooth science and technology activities and return of results" as one necessary issue. A review was begun in June 2006, and an interim report was issued on July 26, 2006.[8]

In the report, the following are mentioned as directions in reforms for system improvement.

- Creation and strengthening of support systems, etc.
- Securing and training clinical researchers and clinical research support personnel.
- Improvement of the environment for promoting research and review/approval (improvement of the framework for promoting clinical research, improving speed and efficiency in reviews and approvals of pharmaceutical products, etc., and joint international clinical trials).
- Participation of the Japanese people (deregulation of information distribution activity on clinical trials, incentives for subjects in clinical research).

(d) On March 30, 2007, MEXT and the Ministry of Health, Labour and Welfare announced a "New 5-Year Clinical Trial Activation Plan."[9] This corresponds to the following plans in the "National 3-Year Clinical Trial Activation Plan" adopted in April 2003.

In the New 5-Year Clinical Trial Activation Plan, the following items are mentioned as issues for achieving a higher level of activity in clinical trials and clinical research.

- Creation of a system of core hospitals and base medical institutions.
- Training and securing human resources to implement clinical trials and clinical research.
- Popularization to and enlightenment of the Japanese people, and promotion of participation in clinical trials and clinical research.
- Efficient implementation of clinical trials and alleviation of the burden on private business.
- Other issues (elimination of obstacles to joint international clinical tests/clinical research, study of a system for reporting the start of clinical research, review of "Ethical Guidelines for Clinical Research," and other matters related to review of "Ordinance on Good Clinical Practice (GCP)," etc.).

3-2 Content of recommendations on training of human resources for clinical research

All of the recommendations discussed in the previous section 3-1 mentioned items related to the training of human resources for clinical research. These will be discussed in detail in the following.

The above-mentioned item (a) recommended securing and training human resources to support clinical research (clinical trial coordinators, biostatisticians, clinical epidemiologists, pharmacists, data managers, etc.). A huge number of data are generated in clinical research. In order to interpret these data and determine the subsequent direction of research, clinical research support personnel who manage and perform statistical analyses of these data are necessary and indispensable. The recommendations for securing (and hiring) this number of clinical researchers and clinical research support personnel include improvement of education for this purpose and providing career paths and economic incentives for researchers.

Although (a) did not present concrete policy recommendations on the training of clinical research personnel for the physicians, who are the main persons carrying out clinical research, the following may be mentioned as concrete efforts related to the item "Creation of a support system for clinical research/translational research."

- Efforts not only to develop "seeds" from basic research to clinical development, but also to tie "seeds" from the clinical viewpoint to basic research.
- Collection of information on world trends, such as new technique and research efforts in clinical research, and so on, and study of the application of those techniques/research.
- Expansion and strengthening of joint systems between physicians and researchers in basic medical science and other fields (in particular, engineering-related and pharmacology-related fields).
- Creation of facilities, institutes, and networks for search-type development of candidate substances for pharmaceutical products and implementation of the search for such substances, and improvement of the research infrastructure, including cell/tissue banks, specialized non-clinical test facilities, etc.

Although these are mentioned in connection with the research support system, if "research infrastructure" in the final item is changed to "training of clinical researchers," virtually the same language describes a human resources training policy, as follows:

- Training of clinical researchers who implement research which not only develops the "seeds" from basic research to clinical research, but also tie "seeds" from the clinical viewpoint to basic research.
- Training of clinical researchers who grapple actively with new techniques and research in clinical research.
- Training of clinical researchers who can actively implement joint research with physicians and researchers in basic medical science and researchers in other fields.

As human resources which are indispensable for promoting clinical research, item (b) mentioned <u>physicians who carry out clinical research</u>, biostatisticians, human resources with a knowledge of regulatory science, data managers, clinical trial coordinators, human resources working in genomics and other technologies, human resources working in informatics, human resources promoting medical-engineering collaboration (information science, nanobiology, engineering), and human resources in the areas of intellectual property and legal affairs. In addition, it is also necessary to improve and expand graduate schools of public health for comprehensive education of these human resources.

Next, assuming that it is necessary to train the physicians who carry out clinical research in medical schools and graduate schools, the followings are mentioned as concrete measures.

- Improvement of the clinical research curriculum in medical school education.
- Education in clinical research and implementation of research in graduate schools.
- Establishment of post-doctoral fellowships for physicians involved in clinical research.
- Education in summer schools and the like in clinical research centers as on-the-job training (OJT).
- Establishment of an evaluation system which provides incentives to physicians participating in clinical research.

As in item (a), (c) also refers to training/securing clinical research support personnel. However, in addition to this, it also mentions the followings as problems related to the training of the physicians responsible for clinical research.

- Inadequacy of human resources for clinical research: As the causes of this, because universities tend to prioritize basic experimental medical science, clinical trials and clinical research tend to be a less important priority. Moreover, because the latter types of work require time, they do not lead to promotions, and as a result, university researchers tend to avoid these fields.
- The weakness of universities, hospitals, research institutes, and others that educate/train human resources for clinical research is also a problem.

Where training of clinical researchers is concerned, the followings were recommended in (c):

- Universities should shift education and research to fields closer to clinical research.
- It is necessary to create an environment in which clinical researchers are fairly evaluated as specialists, and to establish a career path which reflects their actual performance in clinical research.

Item (d) recommends concrete measures in connection with incentives for physicians engaged in clinical trials and clinical research:

- Urge cooperation in core hospitals, base medical institutions, and related bodies in order to improve the evaluation of the clinical performance of physicians and others (including their treatment in hospitals, evaluation of academic society papers, acquisition of degrees).
- Shift the share of Health and Labour Sciences Research Grants and other grants from basic research to clinical trials and clinical research in order to popularize clinical trials/clinical research.
- Secure and increase opportunities for education related to clinical trials and clinical research in the curriculum for physicians and related professions.
- Make it possible for physicians and others involved in clinical trials and clinical research to secure time and financial resources for research.

3-3 Types of clinical researchers required in the future

Summarizing the foregoing discussion, it is thought that the following four types of clinical researchers will be required in the future:

(A) Researchers who have strong ability in both basic research and clinical research.
(B) Researchers who are oriented toward collaborative/interdisciplinary work with other fields.
(C) Specialists in clinical research as such.
(D) Researchers who play a leadership role in implementing clinical trials.

4 Graduate school programs for training human resources for clinical research

First, the current problems in training human resources for clinical research in Japanese graduate schools will be discussed in section 4-1. Next, section 4-2 describes human resources development programs in graduate schools supported by the national government. Section 4-3 presents an outline of the human resources development programs in graduate school medical science departments selected under the national programs in 4-2, focusing on those which appear to be capable of training the "clinical researchers required in the future."

4-1 Current problems in postgraduate training of human resources for clinical research

Because clinical research centers on research through medical treatment, clinical researchers should desirably be persons who possess the fundamental knowledge and skills required in physicians and who have also received training as researchers. It is also necessary to train a large number of clinical researchers of this type. However, a substantially long period of time is required for a physician to become a clinical researcher.

After completing 6 years of medical education (medical school) in order to acquire the basic knowledge, skills, etc. necessary in physicians, physicians are legally required to receive 2 years of clinical training under the New Postgraduate Medical Training System, which was established in April 2004, so as to master a wide range of basic medical capabilities. Then, in order to acquire qualification as a specialist (physician who has received education and training satisfying specified standards in a designated clinical field or disease and passed a test in this specialization), some physicians receive specialized medical training for 3-5 years following New Postgraduate Medical Training.

If a physician wishes to go on to graduate school with the aim of becoming a researcher, he or she must first complete New Postgraduate Medical Training. This means that medical researchers begin their careers considerably later than researchers in other fields. Moreover, it has been reported that persons 30-34 years of age are the largest age group currently entering graduate schools[10], suggesting that many physicians actually complete specialized medical training before going on to graduate school.

The Final Report of the "Cooperating Members Committee on Studying Improvement of Medical Education (MEXT)[10] offered the following recommendations for improving graduate school education based on these point as above.

- Clarification of the purpose of graduate school (training of researchers and training of Physicians), and positioning of medical occupations for research purposes in the university hospital in the graduate school curriculum.
- Implementation of autumn admissions in order to allow physicians adequate time to prepare to enter graduate school after completing New Postgraduate Medical Training.
- Establishment of a graduate school course allowing early advance to graduate school without receiving New Postgraduate Medical Training.
  (As examples of early advancement to graduate school, 17 universities are attempting to establish MD/Ph.D. courses in which persons who have completed the credits required by the university with outstanding records are allowed to enter graduate school medical research departments after completing their fourth year of medical school, and then, upon completing their Ph.D., are readmitted to the 5th year of medical school, and go on graduate.)
- Incorporation of training intended to develop a "researcher's mentality" for personal career path to become educators or researchers in the future in the training period other than the basic training courses of the New Postgraduate Medical Training and required courses.
- Improvement of graduate school efforts to train medical specialists by cooperation between graduate schools and university hospitals.
- Efforts to give a real feeling that receiving the Ph.D. degree is the "starting line" for educators and researchers.
- Clarification of the respective career paths for physicians, clinical researchers, and basic medical researchers, and support for career formation.

If the merits and incentives for physicians going on to graduate school are not clear, there is concern that the number of persons going on to postgraduate education will decline in the future.

4-2 Clinical researcher training programs in nationally-supported graduate schools

As "Support for University Education Reform throughout National, Public, and Private Universities," MEXT provides support for selected programs with distinctive features at universities and graduate schools. The budget for these activities was ¥60.2 billion in FY2007, up from ¥56.2 billion in FY2006.[11]

This includes "Creation of the World's Highest Level Education and Research Centers with International Competitiveness (Global COE, 21st Century COE Program)," "Promotion of Training of Persons in Specialized Occupations Responding to Social Needs (Program for

Promotion of Education in Specialized Graduate Schools, Etc., Program for Promotion of Training of High Quality Medical Personnel Responding to Regional Medicine and other Social Needs, Cancer Professional Training Program)," "Training of Human Resources Capable of Responding to Contemporary Issues and Development of Diverse Functions of Universities (Contemporary Educational Needs Support Program, University Education Internationalization Promotion Program, Program for Promotion of Education Responding to Adult Reeducation Needs, Student Support Program Responding to New Social Needs)," "Advancement/Enrichment of Educational Content/Methods, Etc. Corresponding to Courses (Distinctive University Education Support Program, Graduate School Educational Reform Support Program, Initiatives for Attractive Education in Graduate Schools: Table 3)."

The following will discuss the programs, among those mentioned above, which also function as training programs for human resources in the field of clinical research.

(1) "Initiatives for Attractive Education in Graduate Schools"[12]

The "Initiatives for Attractive Education in Graduate Schools" program (MEXT, Higher Education. Bureau, University Promotion Division, and Japan Society for the Promotion of Science) is a support program which gives priority to active and original graduate school educational programs aimed chiefly at training of young researchers responding to social needs.

In this program, among the medical topics selected in 2005 (19 items) and 2006 (11 items), themes of educational programs related to clinical research were selected, as shown Table 4. Examples of these will be discussed in the following section 4-3.

Table 3 : Outline of the "Initiatives for Attractive Education in Graduate Schools" program

"Initiatives for Attractive Education in Graduate Schools"

(Outline)

- **Provides prioritized support for educational programs to enable young researchers to acquire, in an organized and systematic manner, the attributes newly required in young researchers and the capability to carry our research activities independently, and promotes strengthening of researcher training functions.**
- **Promotes strengthening of organizational development of educational issues and pioneering of new research guidance methods from the viewpoint of advancing graduate school education responding to the needs of the times.**

(Applicable objects)

In principle, applied to the course having a doctoral program.

(Scale of project)

- **The amount of grants provided by the national government has an upper limit of \50 million/year for each item within the scope of the program scale, considering its content, etc., and in principle is provided continuously for 2 years.**

(Budget)

Budget for fiscal year 2006: \4.2 billion (for FY2005: \3.0 billion).

(Record of awards)

- **FY2006: 268 applications were received from 129 universities; of these, 46 items from 35 universities were selected to receive grants. This included 11 items in medical fields.**
- **universities were selected, including 19 items in medical fields.**

Prepared by the STFC, referring to references[11 and12]

(2) "Program for Promotion of Training of High Quality Medical Personnel Responding to Regional Medicine and other Social Needs"[13]

The objectives of the "Program for Promotion of Training of High Quality Medical Personnel Responding to Regional Medicine and other Social Needs" (MEXT, Higher Education, Bureau, Medical Education Division) are to encourage a higher level of activity in university education and promote the training of the high quality medical personnel required by society. This promotion program provides financial support for distinctive outstanding programs for training high quality medical personnel from among programs in applications submitted by national, public, and private universities which have set themes responding to regional medicine and other social needs.[13]

Under this program, the announced themes for applications differ each year. The themes for FY2006 were "Training of physicians responding to unbalanced distribution by field" and "Training of pharmacists for improvement of clinical capabilities," while those for FY2007 were "Training of human resources for clinical research/research support" and "Encouraging female physicians/nurses to enter/remain in clinical work and support for return to work."

The budget for the two themes in FY2007 is ¥1.31 billion. Continuing financial support

Table 4 : Examples of programs selected under the "Initiatives for Attractive Education in Graduate Schools" program (items related to clinical research)

Year selected	University	Specialization	Educational program	Object of program
2005	Gunma University	Graduate School of Medicine, Medical Science Course	Bilateral Evolution and Practice in Education in the Graduate School of Medicine	Fusion of basic medicine and clinical medicine
2005	Kyoto University	Graduate School of Medicine	Horizontal Systematic Medical Research Career Path Formation	Interdisciplinary/integrated medical research
2005	Yamaguchi University	Graduate School of Medicine, Applied Medical Engineering Science Course	Education Program on Applied Medical Engineering Science (AMES)	Fusion of medicine and engineering
2005	Nagasaki University	Graduate School of Biomedical Sciences, Infection Research Course (Note: Emerging infectious disease pathology and control science)	International Infectious Disease Researcher/Medical Specialist Training Program	Training of infectious disease researchers and medical specialists
2006	Mie University	Graduate School of Medicine, Life and Medical Science Course	Training of Researchers in Medical Science/Therapeutics Responding to Region and Times	Fusion of basic and clinical research
2006	Kyushu University	Department of Integrative Biomedical Sciences, Graduate School of Medical Sciences	Reform of Graduate School Education for Activation of Clinical Research	Specialized educational system for clinical research
2006	Kumamoto University	Graduate School of Medical Science, Pathological Informatics Course	AIDS Researcher Training Program	Translational research related to AIDS
2006	Miyazaki University	Faculty of Medicine, Bioregulation Course	Educational Center Integrating Clinical Research and Translational Medicine	Translational medicine from discovery of seeds to clinical application
2006	Yokohama City University	Graduate School of Medicine, Biomolecular and Informatics Medical Science Course	Program for Training Clinical Trial Leaders	Clinical trials and clinical tests
2006	Keio University	Graduate School of Medicine, Medical Science Course	Initiative for Integrated Master/Doctor Education for Encouragement of Cancer Research	Integrated basic and clinical research on cancer

Prepared by the STFC

Table 5 : Universities and programs selected for FY2007 Theme, "Training of Human Resources for Clinical Research/Research Support"

University	Program
Gunma University	Training of Human Resources for Clinical Testing by Postgraduate Integrated OJT
Kobe University	Reform of Clinical Research Education by Advanced CRESP — Development of Clinical Research Expert Specialization Program (CRESP) in the Kobe Local Medical Cluster —
Yamaguchi University	Training of Human Resources for Support of Clinical Research by Graduate School Course — Centering on the "Clinical Test Support Center" —
Kyushu University	Training of Human Resources for Support of High Quality Doctor-Led Clinical Tests — Creation of Infrastructure for Construction of Evidence for the Japanese People —
Ryukyus University	Clinical Research Specialist Doctor and Top Class CRC Training Program
Jikei University	Training of Primary Care Site Clinical Researchers
Kitasato University Keio University Juntendo University	Clinical Research Human Resource Training and Education Consortium — Construction and Implementation of Education System through Domestic and International Collaboration —

Source: http://www.mext.go.jp/b_menu/houdou/19/07/07072516.htm

(approximately 3 years) is given to selected programs.

The object of the theme for 2007, "Training of human resources for clinical research/research support," is for programs in connection with the training of high quality clinical researchers and research support personnel (clinical test coordinators, biostatisticians, clinical epidemiologist, data managers, etc.) with the aim of further promoting clinical research contributing to drug discovery/development new therapeutic technologies and translational research to clinical research.

The universities selected under the themes for FY2007 were announced on July 25, 2007. In the area of "Training of human resources for clinical research/research support," 7 programs were selected from among 30 applications. It appears that programs which are expected to have practical and concrete effects were chosen. Table 5 shows the programs selected.

4-3 Introduction of programs selected under "Initiatives for Attractive Education in Graduate Schools"

From Table 4, educational programs related to the following types of human resources for clinical research required in the future were selected: (A) Researchers who have strong ability in both basic research and clinical research, (B) Researchers oriented toward collaborative/interdisciplinary research with other fields, (C) Specialists in clinical research, and (D) Researchers with a leadership role in clinical trials. The features of the selected programs are outlined below.

(A) Training of researchers who have strong ability in both basic research and clinical research

- Interdisciplinary Systematic Medical Education Career Path Formation (Kyoto University)

[Background]

Considering the current rapid progress and international competition in medical research, strong social demand for return of research results to society, and similar factors, acquisition of more comprehensive, total medical knowledge and technology, acquisition of opinions and ethics that include cooperation with society, independence and originality that contribute to the development of new areas, and diverse international communications skills have become essential conditions.

[Objective]

The objective of this program is to construct a comprehensive and holistic graduate school education system including all persons, which rationally introduces a wide perspective in education in line with the new environment of the times, while continuing to provide the intensive individual education given in traditional postgraduate education in medical fields in the past.

[Content of program]

- Six existing fields of specialization (physiology, pathology, internal medicine, surgery, molecular biology, and neuroscience) are unified in one integrated major course.
- In the integrated major course, in addition to the conventional field of specialization, 12 graduate level courses cutting across basic, clinical, and social medicine are newly established as a systematic educational curriculum unit. (These courses are Cell Biology/Cell Physiology, Development and Morphogenesis, Immunology, Allergy, and Infectious Diseases, Oncology, Genetic/Genomic Medicine, Neuroscience, Lifestyle-related Disease, Aging, and Metabolic Medicine, Regenerative Medicine/Organ Reconstruction Medicine, Pathophysiology, Clinical Research (Clinical Epidemiology/Clinical Innovation), Health and Social Medicine, and Medical-Engineering Collaboration).
- Students take at least one graduate school course while simultaneously belonging to their existing field of specialization, and carry out degree-related research while receiving education/research guidance from both systems until receiving their degree.

(Features and future expectations)

The program is expected to train researchers who have strong ability in both basic research and clinical research by providing an educational program that combines a horizontal element of specialized knowledge in a wide range of medical fields and a vertical element of deep expertise.

(B) Training of researchers oriented toward collaborative/interdisciplinary research with other fields

◦ Medical-Engineering Integrated Practical Education Program (Yamaguchi University)

[Background]

The Yamaguchi University, Graduate School of Medicine, Applied Medical Engineering Sciences (AMES) Course is an independent specialized graduate school which was established by merging the Medical School and Engineering Faculty in April 2001, and is the first school of its type in Japan. Its objective is to train human resources with the wide, creative vision necessary in developmental research on advanced medical devices and materials and theory, responding to new trends in medicine and welfare, based on digitization of biological information. It is the only graduate school in Japan which awards a medical engineering degree (Ph.D.).

[Objective]

The objective of AMES is to train researchers with rich humanity, who are creative, possess a wide vision, and can work actively internationally in the field of medical engineering.

[Content of program]

- As required courses in the basic curriculum in medical engineering, classes in the basic medical curriculum are given for non-medical students (basic anatomy and physiology, basic biochemistry, basic pathology, medical statistics, basic internal medicine, basic surgery, etc.), and classes in the basic engineering curriculum are given for non-engineering students (fundamentals of biomechanics, biosensing, biotargeting, biomaterials, biomimetics, biosystems, etc.).
- The second half of the Ph.D. course comprises a specialized medical engineering course and a developmental research course. Training in experimental and analytical techniques is given to enable students to develop integrated medical-engineering research.
- As motivation for medical engineering, persons from medical backgrounds learn the principles of advanced medical/analytical devices and gain engineering experience through practice in methods of use, while persons from engineering learn medical needs through clinical experience, for example, by seeing actual medical operations, etc.

- The program trains "physicians who have knowledge of engineering" and "engineering researchers who are familiar with the field of medicine."

(Features and expectations)

Linkage of medicine and engineering is no longer a new experiment. However, this type of program, which substantially integrates medical and engineering education and research with its focus narrowed to advanced medical equipment and materials is extremely novel and is expected to have an important effect.

(C) Training of specialists in clinical research

◦ Reform of Graduate School Education for Activation of Clinical Research (Kyushu University)

[Background]

Due to the rapid increase in the content of medical school education, introduction of the new system of clinical training after medical school graduation, etc., students and physician trainees no longer have the luxury of considering graduate school education. Under these conditions, graduate schools cannot fulfill their purpose of training human resources, creating obstacles to research.

[Objective]

Kyushu University will begin educational reform of its medical graduate school program with the creation of a specialized educational system for clinical research as the core element. Prior to respective technical field education, basic education covering the entire area of clinical research is first essential. Although it is necessary to train a large number of physicians for clinical research, young physicians must also acquire qualifications as specialists. For this reason, the creation of a system which allows physicians to attend graduate school as adult students is needed.

[Content of program]

- The creation of a specialized educational system for clinical research in the Ph.D. course and systematic course education will enable students to acquire the capability to perform proper clinical research.
- In order to provide opportunities for physicians to study in the graduate school as adult students, classes will be scheduled on evening or holidays.
- The specialized educational system for clinical research in the Ph.D. course and a basic researcher training system will be established, with free access to both systems.

(Features and expectations)

This program for training specialists in clinical research, which considers the personal career path as a physician, is expected to become a model program for encouraging physicians to go on to postgraduate education in the future.

(D) Training of researchers with a leadership role in clinical trials

◦ Program for Training Clinical Trial Leaders (Yokohama City University)

[Background]

To overcome the weakness of poor international competitiveness in clinical research in Japan, improvement of the system for clinical tests and new drug development/evaluation under physicians' leadership is urgently needed in Japan.

[Objective]

The objective of this program is to train graduate students in graduate school Ph.D. courses as leaders who can widely develop clinical research and clinical tests in order to improve the clinical test system in Japan, raise the level of clinical therapeutics, and improve the system for safe and secure medical treatment.

[Content of program]

- Establishment of a systematic, individual guidance system, including basic knowledge, education, and cultivation of perspectives, spanning multiple fields of medical treatment and research.
- Establishment of an advanced medical

research course and a clinical test expert course.

- The clinical test expert course will take the form of practice in performing clinical tests, and will make it possible to master the processes necessary to implement clinical tests and clinical trials.
- An agreement on cooperation in the training of human resources through development and implementation of an advanced joint scientific training program has been concluded with the Food and Drug Administration (FDA) in the United States, which is responsible for approving drugs in that country, and training at the FDA will be possible in the future.
- An international research education system is being introduced, for example, through a cooperation agreement with the University of Iowa in the US, which allows physicians licensed in Japan to practice medicine.

(Features and expectations)

This program is a graduate school specializing in the training of researchers (physicians) who will serve as leaders in clinical trials and clinical tests. Although this is the only graduate school in Japan with an actual course focusing on the training of clinical trial physicians, the number of graduate schools with this type of program is expected to increase in the future.

5 Conclusion

In spite of the continuing development of science and technology, as in the past, the number of issues facing medicine shows no signs of decreasing. Moreover, the structure of diseases is expected to become more complex in the future due to aging, changes in lifestyle and habits, and globalization. New challenges will include an increase in diseases that had been comparatively rare in the past, the appearance of new medical conditions and infectious diseases, and increased prevalence of compound diseases. Given these conditions, the needs and expectations for medical treatment will continue to increase.

The broad goals for medicine are to ensure that the Japanese people will receive better and more effective medical treatment than in the past in Japan, and at the same time, to enable progress in clinical research in this country. For this, it will be necessary to introduce new systems suited to the times in place of the conventional practices in actual medical treatment, in medical schools and other forms of education, and in research.

It takes more than 10 years after graduation from medical school for a physician to become fully qualified and experienced. Likewise, it also requires about 10 years to become a fully-qualified basic researcher. In either case, whether for a physician or basic researcher, human resources development requires a lengthy period.

To confront today’s complex medical problems, human resources with wide clinical knowledge as physicians, a high level of specialization in medical treatment, advanced knowledge of research, and excellent research skills are necessary. Ideally, each individual should possess all of these qualifications, but in actuality, this may not be possible. It is nevertheless important to attempt to train diverse human resources with a breadth of expertise and high level of knowledge in universities. As discussed in this paper, various universities in Japan are beginning to implement distinctive training programs for human resources in the field of clinical research. As these have only begun, the results will not be apparent until some time in the future. However, the development of human resources who are both physicians and basic researchers is a challenge with which Japan must grapple from a long-term perspective.

Promotion of these types of human resources development programs in graduate schools at the national level will be extremely important for Japan in securing human resources with the high level of expertise necessary in the coming years. This is true of all fields, and not simply clinical research. In the future, it will be necessary to expand programs that support young researchers, including research funding and financial assistance for everyday needs, for individuals participating in these human resources development programs, in coordination with those programs.

Glossary

*1 Clinical research: Medical research implemented for the purpose of improving preventive methods, diagnostic methods, and therapeutic methods for diseases in medicine, understanding the pathogenesis and pathology of diseases, and improving the quality of life of patients (in addition to direct medical research, also includes research in connection with dental science, pharmacology, nursing science, rehabilitation science, preventive medicine, and health science) on human subjects (including research on materials and data of human origin which can designate an individual human).
Source: Ethical Guidelines for Clinical Research (established July 30, 2004 by the Ministry of Health, Labour and Welfare).

*2 Clinical test: Research conducted in accordance with an implementation plan specified in advance by performing interventionary acts such as use of drugs, surgical operations, etc. on human subjects.

*3 Clinical trial : Clinical test performed for the purpose of obtaining the data necessary for application to the Ministry of Health, Labour and Welfare for approval of the manufacture, import, or sale of medical and pharmaceutical products, etc.

*4 Translational research :Clinical research on human subjects using small molecular compounds, polymer compounds, genes, cells, tissues, etc. when the appropriateness of human use has been confirmed publicly from both the ethical and scientific viewpoints.

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2

Trends and Issues in Research on Context Awareness Technologies for a Ubiquitous Network Society

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Information and Communications Research Unit

1 Introduction

The coming years may see the creation of the environment referred to as a "ubiquitous network society" or "ubiquitous information society," in which an inconspicuous system of computers provides diverse types of information to users in various everyday surroundings. The u-Japan Strategy, which is being promoted under the leadership of Japan's Ministry of Internal Affairs and Communications (MIC), describes efforts to realize this kind of environment in the following terms[1]:

- Utilization of ICT without the user's awareness, even though the network is present everywhere around the user (in other words, "ubiquitous").
- Realization of person-to-object (P2O) and object-to-object (O2O) communication by linkage of various objects.

Although the technologies for realizing this kind of environment span a diverse range, in particular, "use of ICT (information and communication technology) without user's awareness" is realized by the field of technology referred to as "context awareness technology."

With this technology, a system obtains information from numerous sensors arranged in the home, workplace, cities, and other spaces where people engage in everyday activities. This is used to determine the details of the user's actions and the constantly-changing condition of the environment, that is, "context." The system then performs the service of providing useful information to the user at appropriate times. To realize this kind of system, the user's actions must be recorded in detail in a computer or by third parties, and in some cases, background information on the user is also registered in the computer. The computer infers the user's current condition, intentions, and so on by comparison with this accumulated information and creates various kinds of convenient communications. However, because context awareness technologies are preconditioned on the fact that details of the user's actions which are intimately related to his or her everyday life are constantly registered in the computer, there is also a danger that the user's personal information may be processed "without the user's awareness."

Several vendors in Japan have already begun to propose packaging of services based on context awareness technology. These technologies are frequently marketing using comfortable-sounding expressions like "*mimamori*" (watch over and protect), but from the viewpoint of R&D, the word that describes this process of continuously obtaining information on a person's behavior is "surveillance," which does not include any nuance of "protection." When discussing the potential of a technology, it is perhaps natural from the standpoint of R&D to emphasize the positive in this manner. However, in order to realize "use of ICT without the user's awareness," it is necessary to accumulate, manage, and manipulate the information obtained by mimamori. Thus, this technology can contribute to information management for the purpose of "monitoring" users. Moreover, if this information is misused by third-parties, the damage may be more serious than a simple leak of information. When considering this technology, this point will require increased study in the future as a factor which may be an obstacle to enjoy the potential convenience provided by this technology.

This paper presents an outline of context awareness technology, and describes the research issues which will be key to the future progress and social acceptance of the technology and the creation of new applications. This is currently a field of intense R&D activity, and some technologies are already on the path to practical application. However, the most important challenge in this field is considered to be the implementation of a safe, secure infrastructure for distribution of "context," which reflects the behavior history of individuals. In R&D in this area, study from diverse viewpoints will be necessary, including system design.

It should be noted that this paper is not the result of a comprehensive survey of research activities. In the following, first, how the context of behavior is treated by computers will be explained to help the reader understand the field under discussion. Next, typical examples of system implementation will be presented and research trends in this field will be introduced. Based on this, the importance of the context operation infrastructure will be described from the viewpoint of creating an environment for realizing a ubiquitous network society.

2 Outline of context awareness technology

2-1 Definition of "context" and context information processing

Dictionaries generally define "context" as related circumstances or background and "awareness" as knowledge, self-consciousness, recognition, conscious, consideration, or the like. On the other hand, for research purposes, "context awareness technology" is frequently defined by citing the definition proposed by the pioneering researcher Dey et al., namely, "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves."[8]

Figure 1 shows an example of the classification of context. Context can be broadly classified into "resource context," which is related to information resources such as image contents, as represented by motion pictures, and the user's context. The user's context can be further divided into "user context," which expresses the attributes of the user's intentions, the intention of current behavior, and the like, and "situational context," which concerns the situation in which the user is placed, weather and location, time, and so on.

Object	Content	Context
Resources	Class, attributes, etc. of information resources	Resource context
User	Attributes, intentions, objectives, etc. of user	User context
	Environment, location, time, etc. of user	Situational context

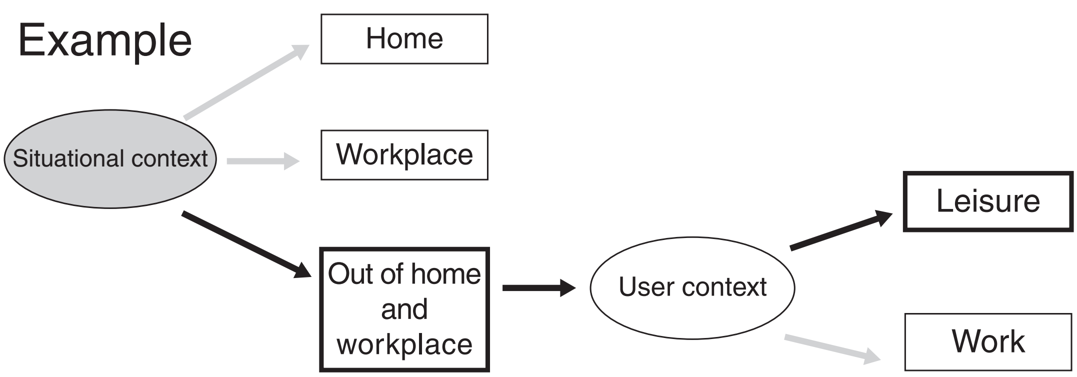

Figure 1 : Classification and examples of context

Resource context expresses, for example, the classification of a movie as horror or love story, the status of the copyright of the contents, etc., while examples of user context might express whether a certain user is currently working or not, in a meeting or not, or similar information. Examples of situational context include the user's location and the weather at that location.

In the example in Figure 1, using the two items of information showing the situational context and the user context, the user's situation can be interpreted as currently being out of the house or workplace on "leisure" and engaged in shopping or some similar activity. Generally, context is expressed by a "state transition diagram" showing transitions between states with defined limits, and software is created on this basis. Contexts are then accumulated and processed as successively changing data within the limits prescribed by the software. The above is an extremely simplified example, but if each context is further subdivided, it would be possible to provide a variety of services corresponding to the diverse states which the user can take. Recent years have seen intensive R&D on this subject. At present, the main targets are behavior modeling, development of context extraction methods and state transition software, and packaging of these functions in actual mobile devices and other equipment. [2,4,10]

2-2 System overview

Figure 2 is a conceptual diagram showing an overview of the configuration of a system which provides information services based on the user's behavior history using context awareness technology. The lowest level in this hierarchical structure is "hardware operation," meaning control of the large number of sensors located in the user's home, office, and elsewhere, the mobile device carried by the user, etc. Based on the raw physical data obtained from this hardware and other sources, the information which forms the basis for the state transitions of constantly-changing contexts is supplied to "context information processing," which is the next highest level.

The next level above this is "display device/ operating device," meaning the devices which actually provide information services and other functions. Conceivable display devices include the user's mobile device, monitors installed in the environment, information display devices, and others. Services and applications, which are assumed to be the highest level, go beyond simple information display and also envision services accompanied by operation, for example, of home appliances. Future possibilities include remote operation of robots and autonomous operation in response to context. The function of these operating devices is termed "information

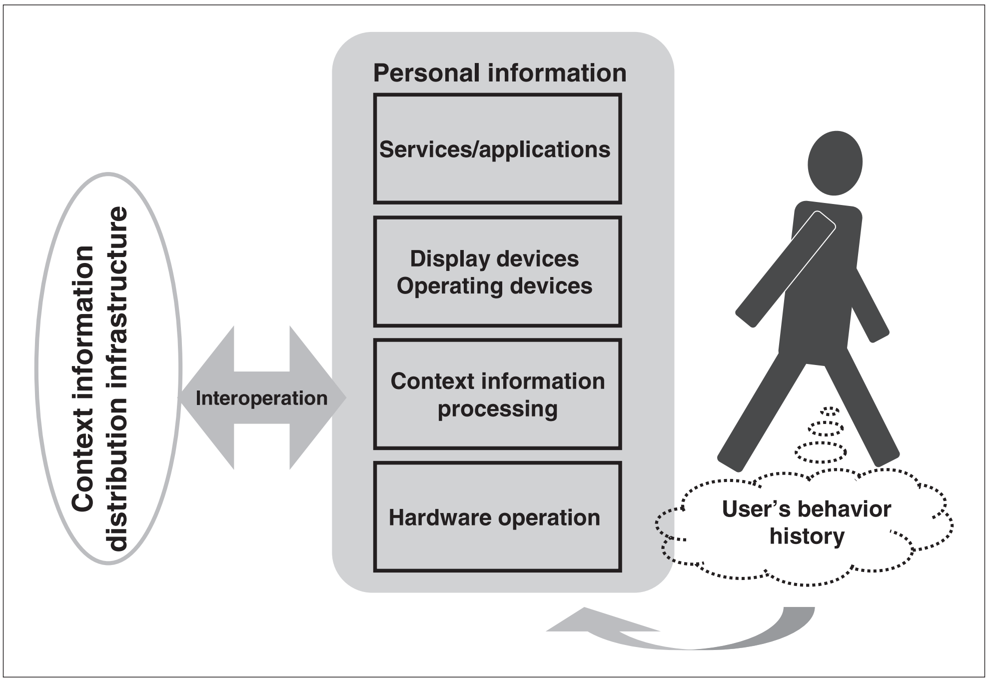

Figure 2 : System overview

actuation," and is considered one key technical trend when describing the future direction of a ubiquitous network society.[18]

The information treated through the system as a whole corresponds almost entirely to "individual information." For this reason, the most important issue for R&D is improvement of functions for dealing with information leaks and unauthorized use by outside parties. This will be discussed in the following section.

2-3 Distribution infrastructure for context information

Cases in which third parties such as internet service providers supply a certain service having some type of added value using the user's context are conceivable. In this, as shown in Figure 2, interoperation of context information with the external "context information distribution infrastructure" is performed via a public network, local area network, or other communications network. What kind of social infrastructure will be necessary in order to provide various services for the user utilizing context information? Because this field is still in the research stage, it is not possible to draw up a definitive blueprint. Generally speaking, however, it is considered possible to realize a model of a technical infrastructure which enables distribution of context information by dividing the system into three functional levels, as shown in Figure 3, "Conceptual diagram of a context information distribution infrastructure."[3,17]

First, at the "user interface technology" level, applications of some type are provided to the user. To configure these applications, it is necessary to combine the different contexts shown in Fig. 1, that is, resource context, user context, situational context, etc. This combination is called a "view." Views specialized to designated users are configured in each application, and are used to call the designated functions.

Next, at the level which provides "middleware technology," functions for creating various kinds of contexts, functions for storing those contexts and retrieving them when necessary, and others are provided. To materialize this functional level as social infrastructure, common international standards for methods of configuring contexts will be necessary. International standards have still not been clearly specified for this area. At present, however, it is considered possible that the technical infrastructures called "Web Service" and "Semantic Web" will play the main role in the provision of services using context awareness technologies.[20]

As technologies which provide functions for interoperation of information resources, technical systems are already available in the form of the above-mentioned "Web service" and "Semantic web."

Web Service is a technical framework for linkage and interoperation, in which software applications which have been constructed in accordance with certain rules are made available on a network. Browsing of application functions is described in a markup language called XML (eXtensible Markup Language), enabling automatic processing by computers.

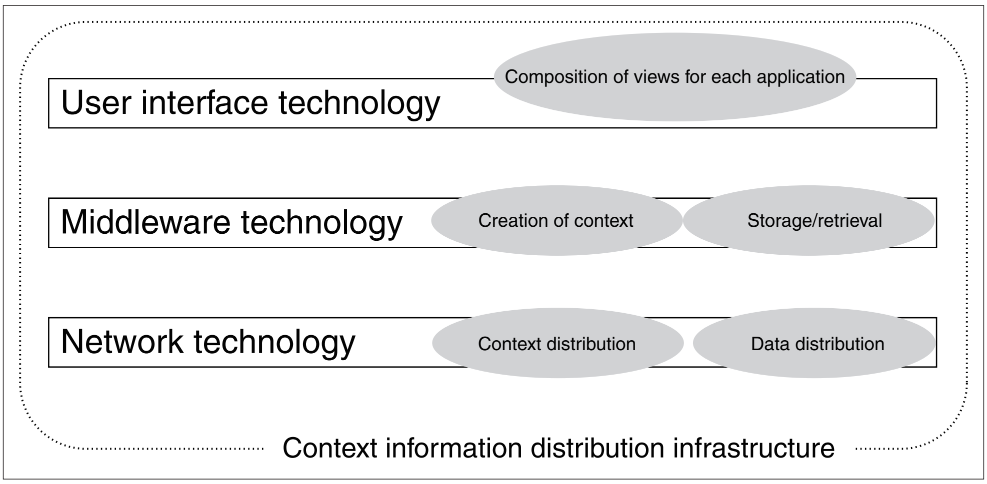

Figure 3 : Conceptual diagram of context information distribution infrastructure

Semantic Web, on the other hand, is a framework for efficient information processing which treats the entire web as a giant database. The contents and processing methods for individual databases are described as “metadata,” and this is used in interoperation of DB.

Finally, the “network technology” level provides a function which distributes the “data” and “contexts” obtained from the sensor network, etc. as physical signals. In this, an existing communications infrastructure such as the internet is used.

Maturity of the context distribution infrastructure shown in Figure 3 will enable interoperation of contexts between the database which stores user context, and the services required by users and databases of various types of resource context, which are the elements of applications. Improvement of this infrastructure also has the potential for the development of new services and applications. Accordingly, improvement of the context distribution infrastructure is also considered extremely important for a ubiquitous network society.

However, in implementing this type of information distribution infrastructure, failsafe handling of personal information must be a key consideration. At present, the international standardization organization for internet-related technologies, W3C (World Wide Web Consortium), is studying a standard called P3P (Platform for Privacy Preferences) as a standard for handling personal information on networks. At present, this is the main standard internationally. This standard describes policy related to privacy in XML, and is available on networks in a form which can be processed by computers. In systems which follow the P3P standard, this policy is interpreted automatically, and restrictions are placed on the extent of use of personal information.[15]

In recent years, the recommendations of W3C alone have been considered inadequate, and further development of this has been proposed.[7,11] As one aspect of R&D on information security, there is pressure for a solution to the problem of newly-registered threats, which sometimes appear to be a endless game of “whack-a-mole.” A large number of research and development problems in this connection must be solved in the future.

2-4 Possibility of creating new services

Next, let us consider the possibility of developing the existing context awareness technology to new services. In cell phones, services using user context have already begun. For example, the author’s cell phone screen has a permanent cartoon character personifying an animal and displays messages based on local topics during trips. It also gives comments, depending on the number of times used and the timing of use. At present, these are only trivial functions intended to create a feeling of psychological bonding with the cartoon character, and have no functions that make more detailed use of context than this. Nevertheless, this example highlights the fact that continuous operation of software on a cell phone and monitoring of the user’s position and use information is quite easy. Technically speaking, it would be a simple matter to use this kind of information in more advanced information processing for marketing and others.

The potential conveniences which can be realized by using context can be outlined as follows. First, from the user’s viewpoint, the following support functions are possible: (1) “Memory-related support,” for example, in jogging the user’s memory and urging attention, (2) “Judgment support,” by providing information to support the user’s judgments when faced with a choice of actions, and (3) “Support for action,” by providing information for assistance or cooperation in the user’s current action when the user is actually involved in some action. On the other hand, from the viewpoint of services, context awareness systems have potential for the following services: (1) Services responding to changes in location accompanying the user’s movements, (2) Services involving acquisition of the user’s behavior history and supply of corresponding information, (3) Services responding to changes in the environment, such as weather and temperature, and (4) Services involving autonomous calling of other services based on the context state.[11,14]

3 Examples of research on context awareness technologies

As examples of research on context awareness technologies, the author visited and conducted a survey at the Media Lab at Massachusetts Institute of Technology (MIT) in the United States, which is conducting advanced research. The following describes research being carried out as integrated research combining architecture and computer science under the name "Home of the Future."[9,10,16]

(1) Example of research on office environments

In the future, our mobile devices may be used to send an increasingly large number of messages to users. In addition to voice mail and email sent by persons, messages also include those generated automatically by computers and other sources. These messages pressure the user to make a rely or some other response, increasing the load on the user. Therefore, research applying context awareness technologies is being carried out in connection with messages which arrive frequently at mobile devices with the aim of alleviating the psychological load on the users who must process these messages.[9]

For example, when a user is studying the content of work with colleagues in the workplace, he or she would not want that conversation to be interrupted by a telephone call from a friend about leisure plans for the weekend. However, if a message with the same content can be displayed on a terminal at an appropriate break in work, the same person would feel no reluctance to reply. This research is attempting to provide a function which will analyze the context of the user's activities during work and adjust the timing at which messages are displayed.

(2) Example from the living environment

The next example is part of a long-term research project which integrates architecture and computer science in a similar way. Assuming a living environment with an extensive sensor system, the work focuses on the development of a mobile device for use in that environment.

Figure 4 : Terminal for operation of home appliances and scene of use (see also color illustration on cover)

Source: MIT Media Lab. Home_n: house of the future

The aim of this research is to support healthier everyday life of users by applying context awareness technology to a terminal (mobile device) in order to control home appliances such as televisions and the like. The terminal includes multiple functions on a single operating screen by adding an email display function and others to an operating screen for television channels, stereo equipment for enjoying music, and similar devices. Figure 4 shows a terminal and a scene in which the terminal is being used in the kitchen.

Particularly in the United States, physical exercise is recommended as an alternative to television viewing because increased time viewing television is thought to contribute to obesity and adult diseases. On the other hand, from the viewpoint of personal freedom of action, a certain amount of time for entertainment is also necessary in everyday life. This terminal is intended to promote natural calorie consumption by encouraging actions other than television watching by an unobtrusive method which users find acceptable. Examples of calorie-consuming activities which are possible with this system include exercising with music and cooking, cleaning, or other housework.

In this environment, as shown in Figure 5, diverse kinds of sensors are installed in the indoor living area, for example, on furniture doors, and actions such as "opened cabinet door" are recorded successively. However, because this record of actions is only a simple enumeration of data, processing at the next highest level is necessary. One research target is to create meaningful user context from this accumulation of data. In addition to this example, active research of this type is being carried out in Japan

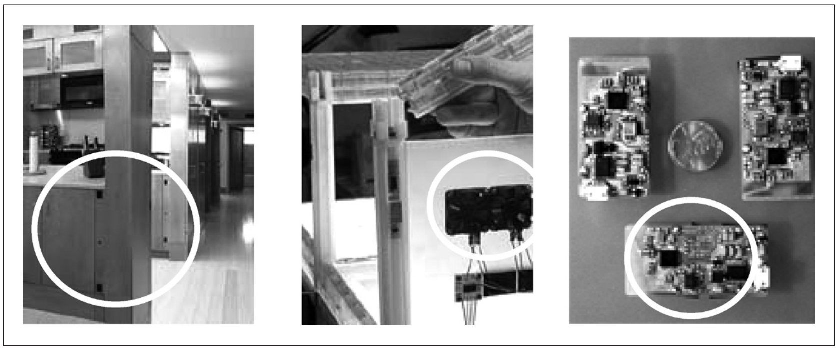

Figure 5 : Examples of sensors installed throughout the home

Source: MIT Media Lab. Home_n: house of the future

and other countries.

In the examples of research and development at MIT, the potential for significant changes in conventional lifestyle patterns supported by new technologies has attracted considerable attention. One motive for R&D is a new way of thinking that anticipates the following changes in attitudes toward health management. This is being reflected in system design concepts.

(1) From treatment to prevention: Change in the purpose of medicine.
(2) From patient to healthy (asymptomatic) person: Response to elderly persons and presymptomatic persons, etc.
(3) From hospital to home: Change in the location of health care.
(4) From periodic examination to real time: Change in the method of obtaining information on diseases.

In other words, these various changes represent a shift in focus from treatment of disease after it has occurred to constant efforts in everyday life to prevent disease. This is considered effective, particularly with adult diseases. To express the response to these changes, the MIT project has proposed the concept “proactive.” As the word suggests, this is a way of thinking that anticipates conditions. This is also a keyword that accurately expresses the image of the new living environment made possible by context awareness technology. Where medicine is concerned, the need for this kind of change has been pointed out for some time, and actual technological support will become possible with the progress in information processing technology, as represented by context awareness technology.

4 Issues for context awareness technology

Ubiquitous network-related technologies span a diverse range. However, the context awareness technology described up to this point is the basic technology for ubiquitous networks. Accordingly, the issues in this technical field correspond directly to numerous topics in research related to ubiquitous networks. Among the issues for R&D on context awareness technology, the following discussion focuses on the two viewpoints of “protection of privacy” and “design of applications,” which are the most important of these issues.

4-1 Protection of personal information (privacy)

Because context awareness technologies handle detailed information on personal behavior, measures to prevent leaks are an essential consideration. Users may willingly provide some personal information to the system if this will make it possible to realize a better living environment for themselves. Because the purpose of this technology is to create a better environment, the major premise is that monitoring of personal behavior and the environment will basically be performed with benevolent intentions. Needless to say, however, a system which is based on this premise will be extremely vulnerable to unauthorized intrusions for malevolent purposes. For this reason, innovation aimed at minimizing leaks of personal information is necessary.

Naturally, study from this viewpoint has already begun. For example, at minimum, reliability at the physical level is demanded in sensors and mobile terminal devices. Under conditions in which an information network is used in the home or an organization, it is necessary to prevent eavesdropping or other theft of personal information by third parties using wireless or electromagnetic environment detection technologies. Thus, research on encryption of transmitted information is important.

Measures are also necessary at higher functional levels of the system configuration. Devices which monitor the user's actions may collect more information than necessary. Therefore, the system must be designed to achieve its purposes with the minimum possible information. For example, processing of context information should be performed only by authorized devices, with sensor functions and hardware placed in a "disabled" condition. Theft of information from sensors and other devices can be prevented by this measure. As another example, in video cameras with an advanced image recognition function, a measure limiting output to primary image information before context analysis is now being studied. To minimize risk, the capacity to recognize objects and persons would be authorized only in other hardware under strict control, and storage of information related to the identification of persons and the content of their actions would be limited to only certain locations. [12]

4-2 Design of applications

Even though applications and services are discussed in research projects on context awareness, these may end in idle speculation. To avoid this, in many cases, applications are being studied predicated on implementation of an actual sensor network. When discussing technologies in this field, the following problems are considered possible.

First, there are issues related to the utility of applications. The actual demand for the applications now under study in various research projects is open to question. In particular, if the method of configuring the sensor network is considered to be the central issue for research, the ideal form of applications will be no more than an auxiliary element. This tendency can also hinder general recognition of the importance of the technical field. The feeling that it is necessary to use comfortable words like "watch over and protect" in connection with context awareness may be a psychological response to the low social acceptance of this field of technology. Because the psychological threshold for context awareness technology generally rises and its social acceptance decreases as the services and applications which this technology envisions become more intimately involved in everyday life, a system design concept which goes beyond this is necessary in the design of applications.

The concept expressed by the word "proactive" in the example from MIT corresponds to this. The creation of this concept or design concept is, in actuality, equally or more important than the development of element technologies related to network technology. Describing this kind of new vision of the living environment of the future is not necessarily easy, but it is nevertheless extremely important for the management of research and development in this field, in which the creation of applications is required.

A second issue concerns standardization of the technology. In the future, it is likely that highly effective services will be created by repeating various repeated trial-and-error efforts after implementation of the infrastructure for context distribution. By analogy with the evolution of today's internet, this kind of practical trial-and-error experimentation occurs in response to financial incentives after common technical specifications have been materialized up to some level. One example of this is competition among venture companies providing services.

The long-term strategic policy "Innovation 25" adopted by the Japanese Cabinet in June 2007 mentions research topics which require "strategic promotion of research and development" by field. One of these topics in the Information and Telecommunications Field is "Construction of the world's most advanced safe/secure ICT infrastructure." As objectives which contributed to the drafting of this policy, the report[17] of a study carried out in FY2006 by NISTEP pointed out the importance of creating four types of "infrastructure" related to ubiquitous networks as social infrastructure which must be constructed in order to realize a "mature ubiquitous society." Although the details of this infrastructure will be omitted here, the research area for context awareness technology corresponds to "middleware technology," as discussed in section 2-3 of this paper.

In order to encourage implementation of infrastructure, management of R&D projects preconditioned on the establishment of a common infrastructure is necessary. It would be wasteful for every project to attempt to cover all the levels of network technology, middleware, and applications shown in Figure 3. For this reason, early establishment of common specifications on which most researchers can agree is necessary for the lower two levels, that is, "network technology" and "middleware." Beyond this, it is necessary to create the conditions for selecting and discarding diverse applications through a trial-and-error process which leaves only desirable applications, and thereby refining the content of services.

5 Conclusion

In promoting context awareness technology, it is necessary simultaneously to use and protect the personal information referred to as "context." This is an extremely challenging issue for research, both from the technical viewpoint and from the viewpoint of system design.

Moreover, even assuming that an adequate environment for handling personal information can be created, good services will not necessarily exist from the initial stage. There are also cases in which such services are newly devised for the first time in the process of popularization and actual use of the technology. In other words, this is a type of chicken-and-egg paradox, in that evolution of the technology and maturation of the social system must progress together.

For this reason, while carrying out research and development on individual element technologies, a vision of the kind of society which we wish to create, and a system design concept based on that vision, are also necessary. In an example from work at MIT, concepts for the living environment surrounding medical care in the future were presented based on the design concept "proactive." This is an example of the kind of design concept proposed here. In research and development in this field, discussion aimed at creating this kind of new vision is essential.

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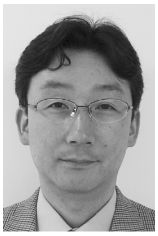

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3

IT-Based Industrial Development in India and Trends in Human Resources Development with the Aim of Realizing a Knowledge-Based Society

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1 Introduction

It is generally accepted that the steam engine was the driving force of the Industrial Revolution in the 18th century. Steam is a type of power which is derived from fossil fuels such as coal and oil. However, with changing times, it appears that knowledge is replacing the fossil fuels as the driving force for social change. India, like Japan, is an Asian nation, and has drawn up strategies to become a knowledge-supplier for global society and is trying to secure its competitive advantage in the next-generation global economy on this basis.

India is also one of the BRICs countries (Brazil, Russia, India, and China), and is in the midst of rapid economic growth spurred by liberalization of its economy and growth in IT-related industries, giving the country a rapidly increasing presence in international society. According to one estimate, India is expected to become the world's third largest economy by around 2032.[1] According to a 2006 report that studied 100 emerging companies located in fast-growing regions including the BRICs,[2] Indian companies already account for 21 of these 100 companies, and seven of these are classified as "companies that have developed technological capabilities into innovation in the global economy". As these reports suggest, India's potential is already recognized by the world.

Unlike Japan, where the declining birthrate is a major problem, in India, young people under the age of 25, who will play a key role in the next generation, account for 50% of the country's total population of 1.1 billion. In addition to an abundant workforce, India's competitive superiority can also be attributed to the fact that it is the world's largest democratic country, its people have a high level of English proficiency, and labor wages are relatively low. However, the most important factor may be India's social system, which continuously produces human resources with high potential.

Although the Japan-India Science and Technology Cooperation Agreement was drawn up in 1985, the relationship between the two countries showed little subsequent development in science and technology. However, in the last few years, the respective leaders of Japan and India have successively visited their counterpart countries, and in August 2007, the Prime Minister of Japan visited India to make a joint statement on the "Roadmap for New Dimensions to the Strategic and Global Partnership between Japan and India," reconfirming the framework for cooperation between the two countries in fields of science and technology including information and communication technology (ICT), nanotechnology, life science, and aerospace research. As seen in an example in life science, in which Japan's RIKEN and the Ministry of Science and Technology of India concluded a science and technology cooperation agreement in December 2006, the countries also seem to be developing a closer relationship than in the past. Thus, the relationship between the two countries is continuing to develop rapidly.

Based on this background, this report reviews the development of India's IT sector and then summarizes trends in bioinformatics, which is highly compatible with IT and has the possibility to create a huge potential market. Various Indian projects for developing human resources are also discussed, as this is a prerequisite supporting the sustained growth of India as its targets a knowledge-based society and is already being implemented at various levels of industry, academia, and government.

2 IT industry in India

2-1 Strength of the software industry

India's rapid growth is supported by IT-BPO (IT and Business Process Outsourcing: hereinafter referred to as IT industry),*1 centering on software. In this industry, hardware-related business accounts for a mere 20% of the whole, while the entire remainder represents the contribution of software and service-related businesses.

India has grown to be a major global player in the software business. Figure 1 shows the changes in the market scale of the IT industry in India and its share of GDP. The entire market of the IT industry has achieved growth. Exports have achieved particularly remarkable growth and are estimated at US$31.9 billion in 2007, or almost 18 times more than in 1998 (US$1.8 billion).[3] This amounts to about 60% of world offshore IT-BPO (outsourcing to other countries). As a result, the IT industry is projected to account for 5.4% of India's GDP in 2007.

In particular, software development and services excluding hardware have grown by more than 30% annually, of which about 80% is exported, thereby becoming India's largest export industry. Exports in 2006 were mostly to English-speaking countries, with 67% to United States and 25% to Europe (of which 15% was to the UK). Only 1.5% was to Japan.[4] In the business area of software development and services excluding hardware, the direct labor force with a high level of expertise is forecast to reach 16.3 million in 2007 from 190,000 in 1998.[3] Although it is also necessary to consider the supporting labor force in addition to the direct labor force, it is possible to calculate that only 0.2% or less of India's population is creating 5.4% of GDP.

A detailed breakdown of software shows that business process outsourcing from companies in the US and Europe is the main component, followed by IT services such as customized application development and application management, and then by client relationship business such as call centers, and back office operations using IT, such as financial accounting and human resources management.

The style of India's software business has

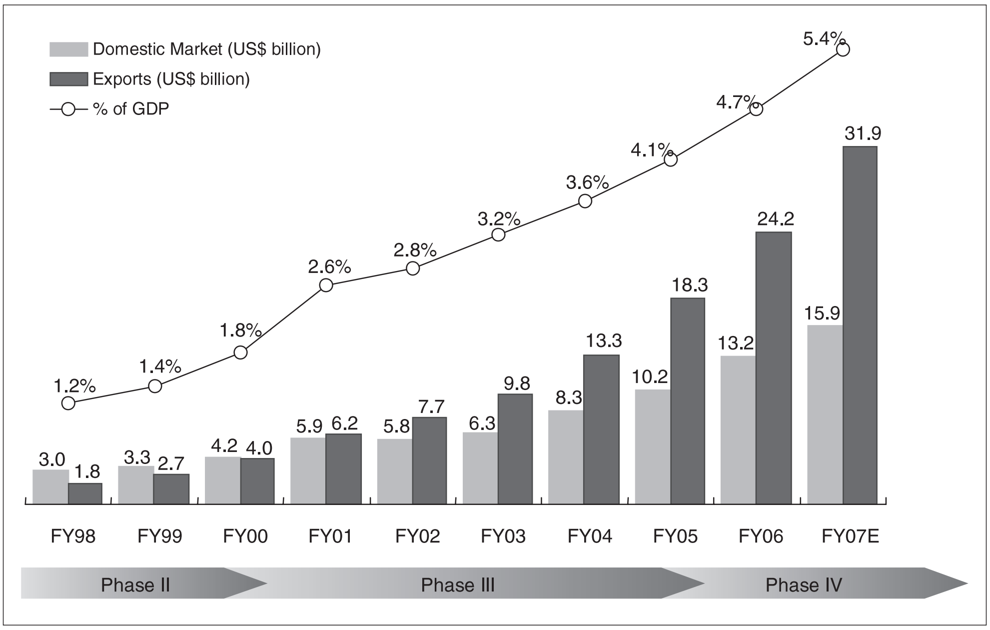

Figure 1 : Trend in market size of IT industry in India and its share GDP (* 2007 estimated)

* Including hardware. Phases correspond to those in Table 1

Prepared by the STFC based on Reference[3]

Table 1 : Changes in software business form in India

Years	Phase	Business form	Business location	Remarks
1985-1995	Phase I	Contracting out from western companies	On-site	Merit of low labor cost
1995-2000	Phase II	Change from contracting out to development business	On-site	Recognization of high quality and productivity
2000-2005	Phase III	Development of software with highly confidentiality	Off shore	Recognization of high security
2005 ~	Phase IV	Development of global scale systems	Off shore	Expectation of innovation in addition to cost, productivity, quality and security

Prepared by the STFC

changed over time, and can be classified largely into 4 phases (Table 1). Until around 1995, India was mainly a subcontractor for European and American companies, and its attractiveness was based on low cost (Phase I). However, around 2000, not only India's low cost, but also its high quality and productivity were recognized, and development businesses increased from simple subcontracting business (Phase II). Around 2005, in addition to cost, quality, and productivity, India was successful in winning the confidence of customers, which made it possible to receive orders for business that treats highly confidential information such as client data. Simultaneously, offshore software development performed locally in India has become the main stream, replacing the on-site business mode that required the subcontractor to visit the client (Phase III). This contributes to cutting the overhead costs associated with software development, but can also be regarded as proof that Indian companies have succeeded in gaining the confidence of clients. Simultaneously with this change in business forms, the relative importance of business for domestic consumption and foreign export has changed places, with exports now far exceeding domestic consumption (Figure 1). Since the year 2005, Indian companies have played an increasingly important role, as seen in the increase in orders for large global-scale system development projects such as integrating branch systems of multinational corporations scattered around the world (Phase IV).

This growth trend appears likely to continue for some time, and it is forecasted that exports of India's IT industry will surpass US$60 billion by the year 2010.[4]

The current size of investment in research and development by India's government is very small compared to that of the US, the European countries, and China, and the budget of the Ministry of Information and Telecommunication of India is much smaller than those in other fields. However, the market in India generated by outsourcing of software research and development from other countries was US$1.3 billion in 2003, but is forecasted to reach US$9.1 billion in 2010.[5] At a glance, the amount of investment in R&D in India still seems to be small, but it is necessary to note the rising trend in the volume of advanced outsourcing work such as structural analysis using CAD/CAM, or "engineering," embedded software, and research and development. From this viewpoint, the actual picture is that outsourcing of research and development by foreign companies is providing substantial support for R&D in India. It is also noteworthy that major corporations outside of India have recently positioned India as a location for R&D facilities to further outsource

Table 2 : Examples of investment in India by major overseas corporations

Company name	Investment period and investment amount
IBM, U.S	US$ 6 billion during 2006~2009
Microsoft, U.S	US$ 1.7 billion during 2005~2009
Cisco, U.S	US$ 1.1 billion during 2006~2009
Intel, U.S	Investment of US$ 1.0 billion including US$ 0.25 billion in venture fund in India
SAP, Germany	20 million Euros
Dell, U.S	30 million Euros during 2006-2009
BOSCH, Germany	US$ 0.2 billion for the next 3 years
Boeing, U.S	US$ 100 million for maintenance-related facilities and more than US$ 85 million for training support facilities such as flight simulators
EADS(Airbus), France	US$ 2.6 billion for the next 15 years

Prepared by the STFC based on Reference[3] knowledge-based business processes (Table 2).

2-2 Effect of US orientation on the development of India's IT industry

The reason why India is focusing on the IT industry appears not to be the result of selection, but rather, the result of a process of elimination.

In the 1980s, India had a poor infrastructure, with domestic industries limited to agriculture, steel, and the like. At the same time, India had a culture which places a high value on education, and as a result, possessed a large pool of human resources with mathematics-based science and engineering backgrounds. As IT does not require a large infrastructure, it was one of the few options available for utilizing human resources with this kind of science and engineering background. In addition, domestic circumstances peculiar to India accelerated the flow of human resources into the IT industry. The IT industry in India was focused on overseas markets from the outset, and as such, the development of a merit system was a natural outcome. Aspiring to a career in the IT industry offered a chance to escape the traditionally-prescribed way of life and play an important role in business. Thus, talented human resources concentrated in the IT industry in a very natural fashion and won an excellent reputation in the global economy, resulting in today's growth in India.

Up to the present, India, which achieved outstanding growth in the IT industry, has been consistently oriented toward the United States as an object of business. As mentioned earlier, about 70% of software and service exports are to the US. The background reasons for this were that both countries use English as their first language, and many students from India went to US universities to study advanced IT and/or academic subjects. In 2006, 76,000 students from India were enrolled in schools in the US, making India the largest "supplier" of overseas students for the US.[6] Of that number, 74% were in graduate schools. This suggests that Indian brainpower is playing an important role in cutting-edge research in the US, including software development.

Most overseas students find jobs in US, and after a few years of hard work, are accepted in society and advance to higher positions.[7] Recently, these talented people have returned to India, thus creating a return flow of intellectual talent to both domestic companies and American corporations in India. It is difficult to offer exact figures, but during the two years 2003-2004, the number of returning US residents of Indian descent is estimated to be somewhere between 10,000 and 40,000.[8] Even more than the cheap labor cost in India, the fact that these talented people had become accustomed to the American way of life and business practices, extending as far as product development methods, was extremely attractive for American corporations from the viewpoint of actual business. In this context, the relationship between India and the US is growing progressively stronger.

One example of India's focus on the US can be seen in the active acquisition of software quality certifications by Indian companies. In the US, there is a tendency to emphasize the importance of quality-related certifications such as CMM (Capability Maturity Model)*2 when outsourcing software-related business. Worldwide, 120 companies have achieved Level 5 in CMM, which is the most difficult level, and of this number, 90 are in India.

In addition to CMM, many companies in India have obtained various quality certifications which American companies emphasize when outsourcing to non-US companies (Figure 2). Although there are varying opinion as to whether the acquisition of those certifications actually guarantees the quality of software, at least it is a fact that many companies in India have actually acquired various quality certification that are considered difficult to achieve, and such certification helps them in winning new business.

The emphasis on quality may be only one example, but India's consistent orientation toward the US level in education and business has had the effect of building the country's actual capabilities as a world-class player in business. In other words, the US has cultivated world-standard capabilities in India, and this has contributed to the development of India's IT industry.

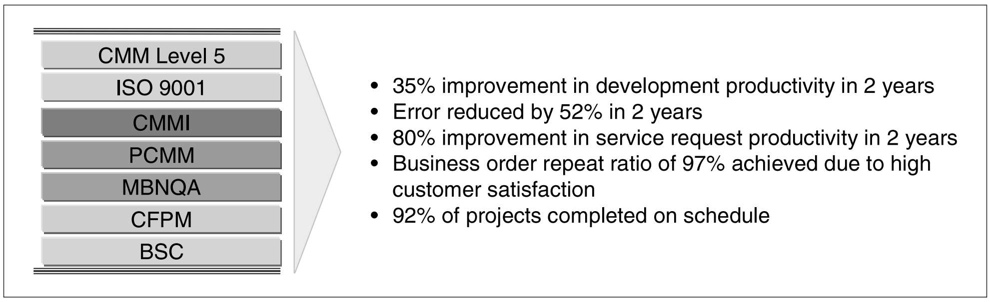

Figure 2 : Example of quality improvement initiatives taken by major software corporations in India

CMMI Capability Maturity Model Integration
PCMM People Capability Maturity Model
MBNQA Malcolm Baldrige National Quality Award
CFPM Cross Functional Process Mapping
BSC Balanced Score Card

Source: Reference [9]

3 Bioinformatics as the next target for the IT industry

The biotechnology field is attracting active investment in R&D in Japan as well as in Europe and the US. Within the field, bioinformatics, which is highly compatible with the IT industry, is expected to become fundamental technology.

Among trends in biotechnology worldwide, the main stream is comprehensive data measurement, which is termed High Throughput. The volume of data which must be obtained when using this technology has become extremely large, and has reached a level where data measurement and analysis are beyond human capabilities, making reliance on information technology inevitable.

Bioinformatics is a new academic field of science and technology which has developed at the border between biological science and computer science in order to grapple with problems like those mentioned above.[13] In fact, recently, there have been a rapidly increasing number of examples in which new findings were obtained through the use of information technologies such as comprehensive analysis technologies employing applied mathematics employing external database which are simultaneously massive in size and diverse in content.

Figure 3 shows the technologies included in bioinformatics on the axes of life information and application/development. To advance into the post-genome era and commercialize products on this basis, it is necessary to handle large volumes of life information. In order to cope with the increase in life information, research on bioinformatics is progressing in a form in which biology is supported by information technologies such as simulation technologies (algorithms, etc.) and database management technologies.

Bioinformatics is positioned as a fundamental technology for biotechnology and has the potential for application in a wide range of areas such as biofuels and agriculture, in addition to life science industry applications such as drug discovery, diagnostics, therapy, and so on, giving enormous market potential to research results. Considering the fact that the global bioinformatics market is forecast to reach US$2 billion by 2010 from US$0.7 billion in 2001,[10,11] future growth can be expected in this research area.

"Science and Technology Trends" has reported twice on trends in bioinformatics, but both reports discussed the US and Europe.[12,13] Therefore, this report will focus on bioinformatics in India. Although India's market presence is still small, bioinformatics is attractive as a field where the country can take advantage of its strengths in the IT industry and future growth is also expected. The following will discuss bioinformatics in India from this viewpoint.

3-1 Focus on bioinformatics

Figure 4 shows the segment shares of biotechnology industry in India and the export ratios of bioinformatics and biopharmaceuticals. The size of the biotechnology-related market in India in 2004-2005 was about US$1.1 billion. By segment, the Bio Pharma segment, as represented by generic drugs, held a predominant share.

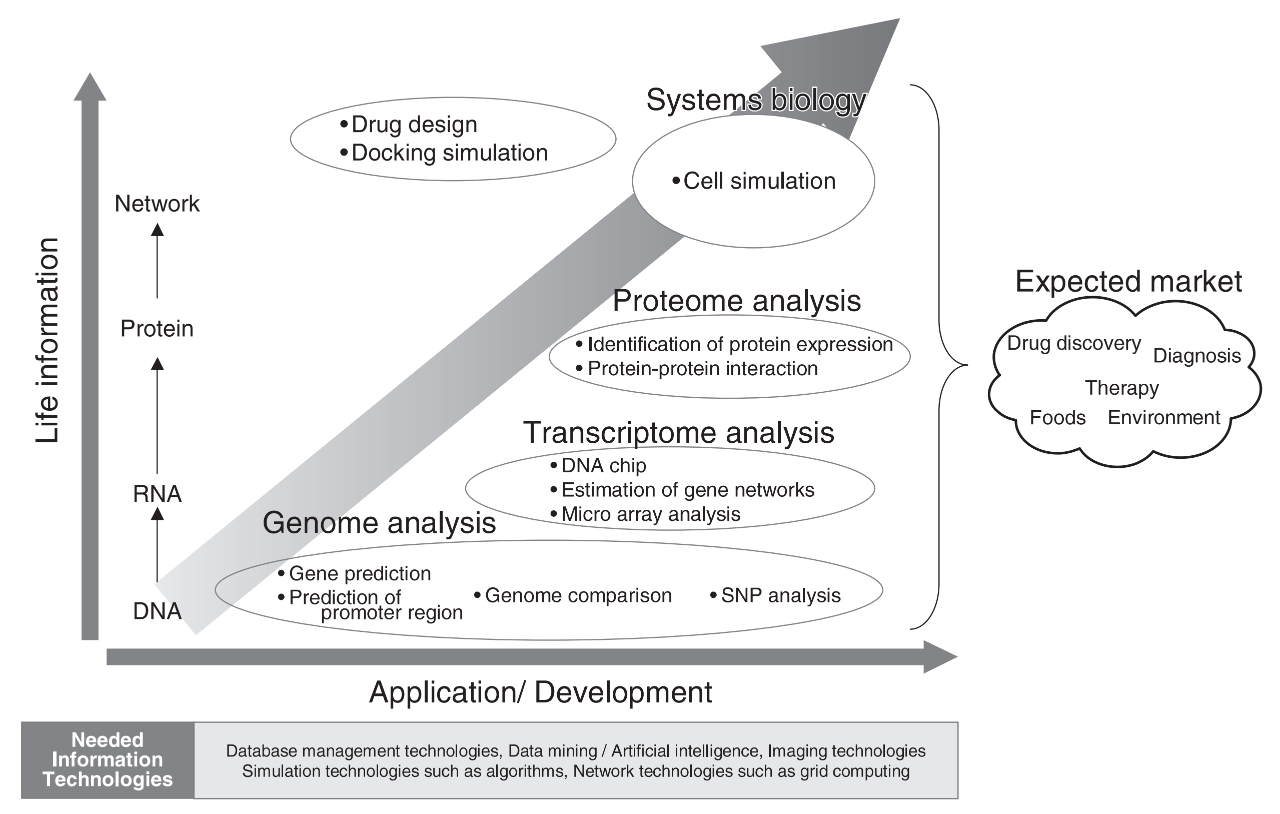

Figure 3 : Target technologies of bioinformatics

Prepared by the STFC based on Reference [14]

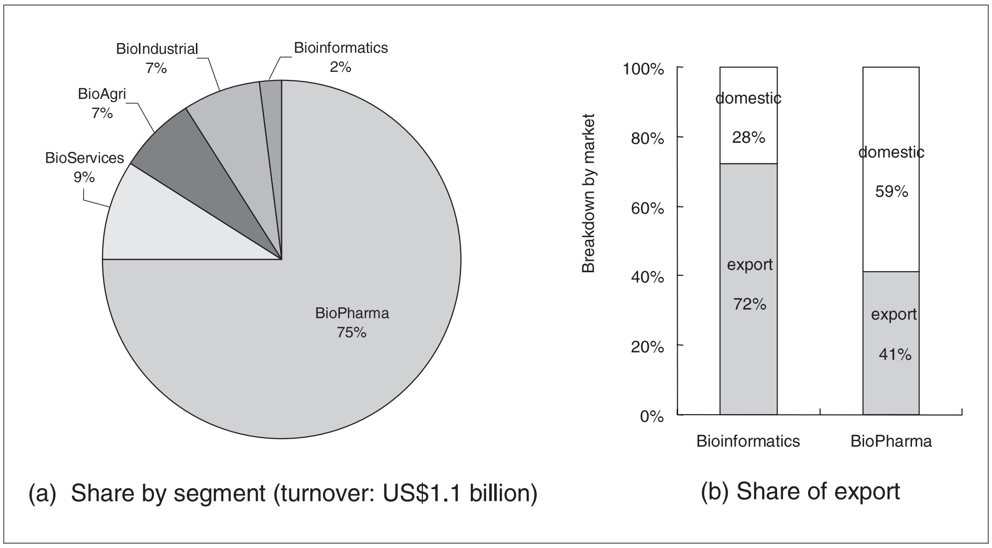

Figure 4 : Share of biotechnology industry in India by segment and share of exports (2004-05)

Prepared by the STFC based on Reference [15]

Although the market scale of generic drugs is large, the important point in this segment is how to synthesize off-patent components and to provide them cheaper. This means the importance of R&D based on science and technology is low. On the other hand, although bioinformatics has a rather small segment share of about 2%, the larger part of the bioinformatics market is for export, unlike Bio Pharma, whose market is 60% domestic. From this, it can be understood that India's technical strength in bioinformatics is highly appreciated in the overseas market.

As noted above, India is beginning to focus on bioinformatics due to its potential market size and its compatibility with the IT industry, in which India has a global competitive advantage. The 10th 5-year national program, which lays

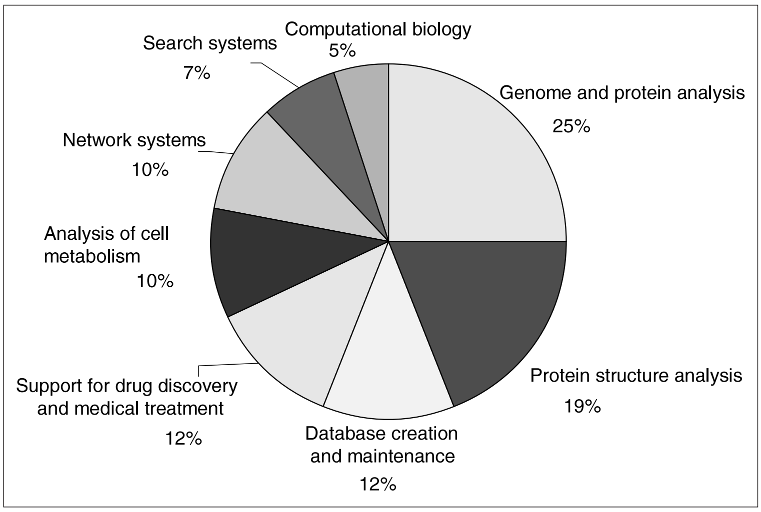

Figure 5 : Breakdown of bioinformatics-related projects under control of Department of Biotechnology, Ministry of Science and Technology in India

Prepared by the STFC

out national strategies from 2002 to 2007, clearly noted the need for research on bioinformatics in the field of information technology,[16] and the importance of bioinformatics is being emphasized in the working group discussion for the pending 11th 5-year national program.[17] In addition, in 2002, NASSCOM, an association of software and service companies,*3 has positioned bioinformatics as one new emerging sector of the future IT industry.[18]

However, as a business, bioinformatics in India is still in an early stage. Although the market size is still small, this field recorded an annualized growth rate of more than 20%, with US$ 23 million in 2004 rising to US$33 million in 2006.[15]

3-2 Efforts in the early stage

Bioinformatics in India is said to have started from research on structure analysis of protein around 1986.[7] This was 10 years before the word of bioinformatics came into widespread use, demonstrating that India recognized the importance of information technology in contemporary biology instantly. In 1986, "Biotechnology Information System Network (BTISnet)" which connects major domestic research institutions, was launched through an initiative of the Biotechnology Agency.

This network continued expanding over time, and now connects 61 research institutions and is used for training of researchers, simulations, and various other purposes.

As early as 1987, University of Pune began offering a master course in bioinformatics. It is surprising to note that India was already aware of the importance of bioinformatics at this time and not only built up a network before the related infrastructure was adequate, but also emphasized the importance of education. Following this, various universities began specialized courses. As India's domestic market for bioinformatics was essentially nonexistent in the 1980s, it can be assumed that India was aiming at education of human resources with a view to overseas markets from the very beginning.

3-3 Current research trend

Thanks to the Indian government's early focus on bioinformatics, many researchers from India are active in key scientific or leadership positions in bioinformatics research in the US and Europe.[7]

To fully understand the situation of bioinformatics in India, the authors examined the database on current biology-related projects administered by the Ministry of Science and Technology, Division of Biotechnology of India (DBT).[19] The results showed that there are 42 bioinformatics-related projects underway at present. Because no mention was made of the details of the projects in the open database, it must be noted that most of what follows are guesses from the titles listed. About half of the database concerned genome and protein analysis and protein structure analysis, followed by

Table 3 : Research facilities for bioinformatics in India

Facility name	Location	Focused fields and characteristics
Bose Institute	Kolkata	Molecular modeling and gene engineering with focus on analysis of structure and binding of protein, genome, drug targeting, etc.
IISc	Bangalore	Structural bioinformatics and molecular designs
Jawaharlal Nehru Univ.	New Delhi	Genomics Provides engineering master courses in computer biology and bioinformatics and PhD programs in computer biology. Provides training courses for post-docs in different fields of physics, mathematics, etc.
Madurai Kamaraj Univ.	Madurai	Gene engineering and structural bioinformatics. Specializes in human resources development training. Has many joint research programs with overseas partners.
Univ. of Pune	Pune	Computer biology and genomics. Has excellent computer and telecommunication infrastructure. Has installed and developed two major databank, AVIS and VIRGEN

Prepared by the STFC based on Reference [20, 21]

database creation and maintenance, support for drug discovery and medical treatment (Figure 5). The breakdown by research institutions shows 5 projects each at the India Institute of Science (IISc) and India Institute of Technology (IIT), and 3 projects each at the Center for Cellular and Molecular Biology and at Madras University.

The Department of Biotechnology has also selected 5 center-of-excellence (COE) research facilities to promote these projects in order to stimulate bioinformatics research (Table 3). Each research institute is involved in a cutting-edge research program, but as will be discussed later, human resources development is also incorporated in the program.

In addition, major IT software companies in India also regard bioinformatics as one of the next growth fields, and the movement toward establishing bioinformatics divisions within these companies is notable.

3-4 Supercomputer facilities specialized in bioinformatics

The effectiveness of simulation technologies is immense, as trials and tests can be executed as many times as time permits and meaningful results that had been overlooked could be recaptured. For this reason, simulation technologies are also positioned as a key technology for bioinformatics research in India.

The supercomputer is the key to a successful simulation, especially, in fields of science and technology involving problems that require extremely long calculation time. However, in India, moves to pursue the world's most advanced hardware performance are rarely seen. Rather, the focus appears to be on research to develop original calculation algorithms and improve software performance. Because large-scale parallel computing is a prerequisite for higher speed in the calculation process, and there are limits to the maximization of computing performance based on hardware speed alone, it is important to develop computational algorithms that maximize computer performance through parallel processing. India is considered to be strong in mathematics and algorithms, and thus is highly competitive in this field.

India has several supercomputers for use in scientific and technical calculations. However, the following discussion will be limited to two facilities with supercomputers that specialize in bioinformatics.

(1) C-DAC (Center for Development of Advanced Computing)

C-DAC is a research and development institution which was established in 1988 as a science society within the Department of Information Technology, Ministry of Telecommunication and Technology Information of India, based on advanced information and telecommunication technology. Like Japan, the US, and China, India has developed commercial supercomputers domestically. C-DAC is a mainstay of the development of supercomputers and provides a supercomputer series called PARAM.

In February 2007, C-DAC announced that it will launch a new supercomputer specially designed for bioinformatics applications.[22]

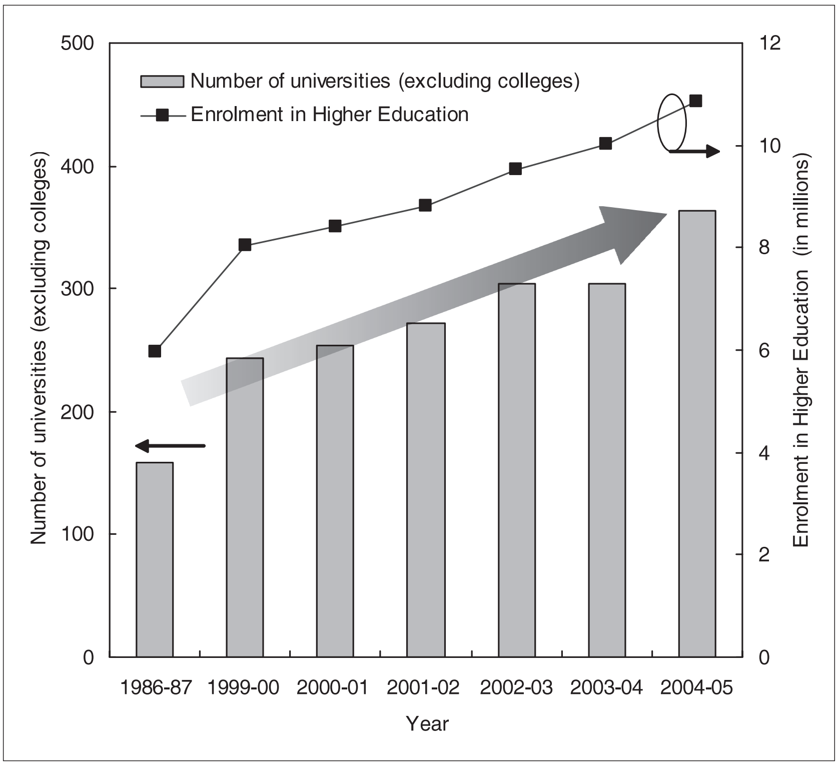

Figure 6 : Annual trend in number of universities and enrollment in institutions of higher education

Prepared by the STFC based on Reference [26]

The aim with this supercomputer is calculation performance of 1.5 TFLOPS. The supercomputer is to be integrated first into the network called Genome Grid, which connects major 40 research institutions in India, and will then be connected with industry for mutual use. Grids are an effective method for connecting remotely-located computer systems physically through a network for efficient use of existing resources. Because this scheme enables many research laboratories and universities to share expensive computing systems, applications, huge volumes of data, and other resources, the cost burden can be reduced, thereby lowering the entry barrier for new researchers.

(2) SCFBio (Supercomputing Facility for Bioinformatics & Computational Biology)

SCFBio was established in 2002 at the Delhi Campus of the India Institution of Technology with financial aid from multiple institutions, including the Department of Biotechnology and others. Its purpose is to develop completely new scientific methods and new software for genome analysis.[23] Priority is placed on research on simulation methods rather than on simulation results. This supercomputer was constructed by combining modules made in the US and has computing performance of 600 GFLOPS. Some of the bioinformatics-related software and tools that have been developed are open to the public.[24]

4 Initiatives to develop human resources through collaboration among industry, education institutions, and government

4-1 Human resources supply system

The rapid growth of India is supported by highly educated human resources with engineering backgrounds. Figure 6 shows the trend in the number of universities and enrollment in institution of higher education. In India, universities and colleges that offer the academic degree of Diploma are classified as institutions of higher education. Compared to 1986-1987, the number of universities more than doubled in 2004-2005, reaching 360. The number of colleges has also increased similarly to universities, to 16,000. This was more than 40 times greater than the number of universities in 2004-2005. The aggregate enrollment in institutions of higher education, including both universities and colleges, is more than 10 million.

Limited to engineering (but excluding science), it is forecast that more than 530,000 students will graduate in 2007-2008, and of that number, approximately 300,000 will be IT engineers with majors in computer science, electrical/electronic engineering, and telecommunications.[25] Compared to other countries which are candidate offshore IT development sites, India supplies 2.5 times more human resources with engineering background than 2nd ranking China (Figure 7).

Particularly outstanding human resources are supplied by the country's leading universities, which include the Indian Institute of Science (IISc), Indian Institute of Technology (IIT), and India Institute of Information Technology (IIIT). However, these institutions graduate only 10,000 students each year. In addition, numerous colleges and professional schools specialize in IT. From this, it can be understood that the supply of human resources that supports India's rapid growth comes mostly from colleges and professional schools specialized in IT.

A study of the compatibility of human resources between institutions of higher education and industry reported that the number of human resources with the skills to be effective immediately upon entering an IT company is limited to 25% of new graduates from universities with technology backgrounds and about 10% of graduates from colleges.[28] If no measures are taken, a shortage of 500,000 persons out of total demand of 2.3 million in IT-BPO-related business is forecast in 2010. The problems associated with this shortage of human resources may have a ripple effect on the whole range of industries based on IT, and an impact on bioinformatics, which relies heavily on IT, is also conceivable.

Quantitatively, the number of human resources that are immediately effective seems quite large. However, India believes that even this number will be insufficient. This suggests that India has a higher awareness of the critical nature of the shortage of human resources than Japan. One reason for such concern can be found in the background strategy of transforming India from the conventional outsourcing of the past to knowledge-based outsourcing. India is attempting to transform itself into a knowledge-based society through the accumulation of the world's most advanced knowledge. From this viewpoint, it is obvious that the shortage of human resources may be a formidable barrier not only to sustained economic growth, but also to increasing the country's international competitiveness.

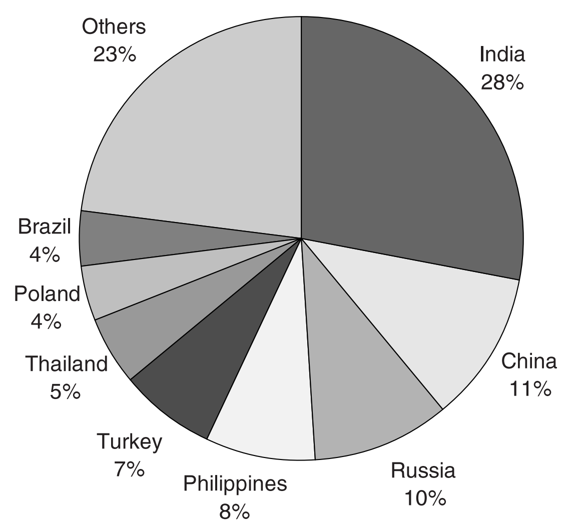

Figure 7 : Ratio of human resources population with expertise in IT offshore candidate countries (2005)

Prepared by the STFC based on Reference [27]

Recently, India's government has drawn up plans to invest US$32 billion to establish 370 new colleges, in addition to 8 new branches of the Indian Institute of Technology (IIT), 7 branches of the Indian Institute of Management (IIM), and 20 branches of the India Institute of Information Technology (IIIT)[29,30] in order to expand and improve its institutions of higher education.

The following presents examples of such initiatives with the focus on human resources development in India through collaboration between industry, academia, and government to date.

4-2 Initiative by government and NASSCOM

The Ministry of Human Resources Development of India, which is responsible for educational policies, and NASSCOM, the National Association of Software and Service Companies in India, have adopted a concept called the Pyramid Approach to improve the incompatibility between the image of the human resources supplied by academia and that expected by industry in IT-related fields. This approach will establish a

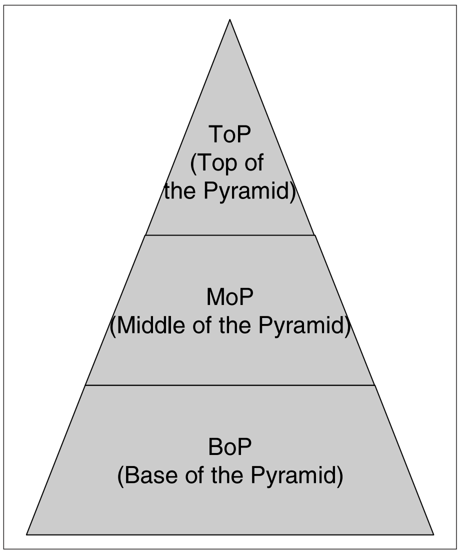

Figure 8 : Human resources development program by Ministry of Human Resources Development in India and NASSCOM (The Pyramid Approach)

Prepared by the STFC based on Reference [31]

hierarchy (Figure 8) classified by the skills that industry considers essential in order to ensure that technologies are mastered corresponding to the level of the educational institution. In this approach, the levels are categorized as ToP, Top of the Pyramid, which aims to ensure that students master the skills required in the future, MoP, Middle of the Pyramid, which aims to ensure mastery of skills that form the core of actual work, and BoP, Base of the Pyramid, which aims to ensure mastery of basic technologies so that the level of IT human resources as a whole can be improved and thereby create a structure pool of talented people that will be useful to industry. This approach to human resources development is outlined below.

(1) ToP: Top of the Pyramid

"Top of the Pyramid" programs are designed to teach high end technologies that may not be required currently but will be necessary in 2-3 years, such as bioinformatics, embedded software, product architecture, DSP, VLSI, program management, etc. The Ministry of Human Resources Development of India is planning to establish 20 branches of the India Institute of Information Technology in the next few years as research centers for this purpose with industry cooperation. Five institutions are to be established by 2008.

(2) MoP: Middle of the Pyramid

The focus of programs at this level is certain mainstream skills in the IT industry which institutions of higher education have clearly failed to teach to students. The aim is to ensure that students master these core skills. This level is assumed to be the area where India will face the largest human resources shortage in the future. Specifically, The Ministry of Human Resources Development of India and NASSCOM are implementing the following programs in academia.

(a) Introduction of student evaluation standards

This program is designed to introduce industry-wide student evaluation standards in order to assist students in understanding their own capabilities. This is also used as an index for measuring the employment aptitude of applying students.

(b) Introduction of Finishing School (Pilot phase)

This program is designed to provide technical and software skills to engineering graduates. Before joining a company, the program offers opportunities for training by consultants in IT industry so that students can learn industry-specific knowledge, skills, management, etc. This is one program on which companies place high expectations as a program for training human resources who can function effectively immediately upon employment. Eight institutions, including IIT Roorkee, are conducting this program as a pilot program for about 8 weeks starting in May 2007.

(c) Execution of IT human resources development program

As a means of filling the gap between industry and academia, this program is designed to offer opportunities for mutual understanding through workshops, training programs, and similar activities. Faculty Training Workshop and the Sabbatical Program offer good opportunities for the teaching staff of universities to find ways to improve their teaching methods and better approaches to important issues.

(3) BoP: Base of the Pyramid

This program is designed to provide basic skills such as network technologies, hardware maintenance, and so on. The NAC (NASSCOM's Assessment Competence) test is conducted to ensure that human resources are suitable for employment through training. Last year, the NAC test was conducted experimentally in Rjasthan State with 2,500 applicants. The results of the test were announced in March 2007, and a Job Fair was organized under the co-sponsorship of the Ministry of Information and Telecommunication of India and the state government. The NAC test is scheduled to be offered in various parts in India by the end of 2007.

4-3 Human resources development for bioinformatics at universities and research institutions

As one example of human resources development for bioinformatics, India is involved in a program which specializes in human resources development at bioinformatics research centers (COE) (Table 3). It is especially interesting that Jawaharlal Nehru University is offering training programs to transform post-docs from different fields such as physics and mathematics into bioinformatics researchers.

Apart from these COEs, various research institutions throughout the nation are also offering seminar programs to train people to use bioinformatics as a tool, and are actively promoting human resources development in the field. In 2005, these short term training programs included more than 80 courses with more than 3,000 researchers, teaching staff, and students who are studying the use of bioinformatics in various fields of biotechnology.[21]

4-4 Initiatives by software companies

(1) Training program spanning industry and academia

In addition to programs to educate human resources who can be effective immediately on employment while such persons are still students, some major software companies in India are also attempting to attract global human resources from abroad (Table 4). This shows an intention to attract excellent human resources who are likely to be future leaders from around the world, and to learn the needs and cultures of their original countries.

Most of the companies provide substantial internal training programs, some of which have facilities that can train 5,000 employees at a time. In most cases, companies provide internal off-the-job training for several months in order to train employees in advanced skills.

One reason why such huge human resource development programs are possible is full-time recruitment of numbers of teaching staff from universities as internal training experts. There is also a system to enable current teaching staff of universities to use sabbaticals to learn the needs of companies and leading technologies. This system promotes reeducation of the teaching staff of universities and ultimately is reflected in the university's education program so as to fill the gap between industry and academia.

(2) Movement toward acquisition of human resources at the global scale

Even with India's rapid economic growth, the rapid rise in the salaries of IT engineers has become a problem. The annual income of employees in the IT industry is already

Table 4 : Example of human resources development programs by a major software corporation

Name of program	Details
Campus Connect	Initiatives to further strengthen ties between industry and academia to develop IT industry, started in 2004. Provides technical training courses, seminars, and so on to train students in the needs of industry and to develop IT experts who can step into industry and be effective immediately.
Global Talent Program	Human resources employment program especially for students studying in U.S universities.
InStep	Global internship program starting in 1999. Program is active all the year round, with 12,000 applications submitted from around the world so far.

Prepared by the STFC based on Reference [9] overwhelmingly higher than in other industries, and has risen extremely rapidly in recent years. In 2004, the income level of new recruits rose by 13% annually, while that of project managers rose 23% for the year.[27] This situation has also been accompanied by appreciation of the Indian rupee, which is continuing to dilute the advantage of lower labor costs in the Indian IT industry. As an additional problem, the increasing number of overseas companies setting up operations in India, as mentioned previously, has made it more difficult to secure high quality human resources in India than before.

Indian companies are looking overseas in order to cope with these problems. One example of such efforts is the application of a "Global Delivery Model." Although this approach was originally considered to be a framework for a decentralized management system for optimizing projects, securing excellent human resources now appears more important. In spite of Indian's 1.1 billion population, Indian companies are accelerating moves to recruit excellent human resources internationally.

One example of application of this approach can be seen in China.

India is trying to strengthen its ties with China, which has rich human resources in the IT field and is also enjoying the same remarkable economic growth.[32] Like India, China has achieved rapid progress in its IT industry recently, and has the second largest supply of human resources after India, but the annual salary of China's IT engineers has not risen as sharply as in India. Therefore, major software companies in India have established operations in China and are developing a large-scale presence in that country in order to secure excellent human resources, as well as to win orders from Western companies with operations in China and take advantage of the huge Chinese market. One example is a company that already has operations in Shanghai, Beijing, Dalian, and Guangzhou and is planning to establish a Global Delivery Campus (GDC) in Nanjing[33] which will be large enough to accommodate a staff of 2500 and includes a development center, training center, convention center, recreation facilities, and accommodation facilities. Some companies envision establishing a foothold in China in order to penetrate the Japanese market, for example, by taking advantage of the fact that China has a larger number of Japanese-speaking human resources than India. China will also benefit from this arrangement by increasing employment and learning India's advanced project management capabilities. Consequently, this appears to be a win-win relationship that serves the interests of both countries.

In addition to China, India is attempting to establish a similar relationship with Brazil, which serves mainly as an offshore base for North America.

5 Conclusion

The rapid economic growth of India in recent years has been supported by the IT industry, centering on software. India has grown to become a major power in software with a 60% world share of the IT offshore market. As India's domestic demand was small, the country was inevitably forced to look to the global market. The current positive economic spiral is considered to be the result of India's orientation to the United States, which has led the world in both the educational and business fields from the dawn of the IT age. Nevertheless, India would not have achieved such impressive growth without human resources with the knowledge and skills to win recognition in the US, which is the world's leader in the IT industry. Moreover, there is no doubt that India's strength in software has contributed to the current economic strength of India as a whole.

The next target market for India is the huge biotechnology industry. In particular, the country as a whole is starting to focus on bioinformatics, which is compatible with the IT industry and is an infrastructure technology for biotechnology. The size of the potential market which may result from research outcomes in bioinformatics is incalculable. It is surprising that India realized the importance of bioinformatics 10 years before the term itself began to be used, and not only constructed networks in an environment with inadequate infrastructure, but also have focused on the education of human resources for the field.

Human resources with engineering training received in higher education have supported this industrial growth. However, even India, with the second largest population in the world, is facing difficulties in securing the necessary human resources due to excessively rapid economic growth. The shortage of necessary human resources will of course be detrimental to the sustained growth of the economy, and will become a serious barrier to improving international competitiveness. Therefore, India is implementing various initiatives in order to develop human resources to fill the gap between the human resources produced by academia and the needs of industry by expanding and improving its institutions of higher education.

India has a high awareness of the critical nature of the shortage of human resources, and is active in both human resources development and securing human resources internationally. As the reason for this, India aims to develop as a knowledge-based society and recognizes that its human resources will be a driving force in pioneering the coming new era. India's aim is nothing other than development as a knowledge-based society by transforming its economy from conventional outsourcing to outsourcing in knowledge industries based on outstanding human resources. India has a population of more than 500 million under the age of 25, and is steadily increasing the number of institutions of higher education. However, we should note the fact that even India is trying to secure outstanding human resources at the global scale.

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Glossary

*1 According to the definition of India's National Association of Software and Services Companies (NASSCOM), the term of IT-BPO means the entire industry that includes IT services, BPO (Business Process Outsourcing), Engineering Services and R&D, Software Products, and Hardware. In this report, we use the term "IT industry" in basically the same sense.

*2 CMM: Capability Maturity Model. CMM was developed by the Software Engineering Institution (SEI) of Carnegie Mellon University in the US with the support of the National Defense Agency to systemize and popularize best practice in software development operation. The project organization prescribes 5 stages based on the capability maturity level.

*3 NASSCOM: National Association of Software and Service Companies. This is a business association consisting from more than 1100 member companies, of which 250 are overseas companies.

Abbreviations

C-DAC: Center for Development of Advanced Computing
DBT: Department of Biotechnology
DSP: Digital Signal Processor
IIIT: Indian Institute of Information Technology
IIM: Indian Institute of Management
IISc: Indian Institute of Science
IIT: Indian Institute of Technology
NASSCOM: National Association of Software and Service Companies
SCFBio: Supercomputing Facility for Bioinformatics & Computational Biology

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4

Research and Development Trends in Solid Oxide Fuel Cell Materials
— From the Viewpoint of Electrolyte-Related R&D as Key —

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1 Introduction

Fuel cells (FCs) convert the chemical energy of fuels directly into electrical energy and therefore take on high generating efficiency even in small-scale systems. FCs also produce high quality waste heat which can be utilized effectively. Unlike conventional primary cells, which reach the end of their useful life when the reactant substances are consumed, and secondary cells, which have the drawback of reduced performance due to the buildup of unnecessary products with repeated charging, the generating performance of FCs can be maintained as long as fuel is supplied, and depending on the fuel selected, FCs discharge virtually no air pollutants. Among the various FCs technologies, solid oxide fuel cells (SOFCs) are particularly attractive, as generating efficiency is high, the FCs supply both heat and electricity, and a diverse range of fuels can be used. As a result, this type has been the object of intensive R&D (research and development) worldwide in recent years. In comparison with other types of FCs, SOFCs have high thermal efficiency and excellent long-term performance stability, and assuming the establishment of cell and stack production processes suitable for mass production, a substantial reduction in system cost can be expected. Specifically, because the systems studied to date operate in the high temperature range, it is possible to achieve an electrochemical reaction at the electrodes simply by supplying fuel and air without using an expensive noble metal catalysts, which mean that low cost component materials can be used in the cell.

This article will review the background and expectations placed on SOFCs R&D and the current status of technologies in Japan and other countries. First, the operating principle and structure of SOFCs are introduced. In particular, the current state of R&D on the electrolyte and electrode materials used in SOFCs and the features required in those electrolytes and related issues in high temperature SOFCs are identified. As a solution to these problems, methods of elucidating the ion conduction mechanism and damage/deterioration mechanism are described. On the other hand, as a completely different approach aimed at solving all of the technical problems of high temperature SOFCs at once, R&D on novel electrolytes with lower operating temperatures than the conventional systems have attracted considerable attention. This article will propose a method of searching for suitable electrolytes in low- and medium-temperature operation.

2 Background and expectations placed on R&D on SOFCs

2-1 SOFCs as high efficiency generating systems

The relationship between the scale of various types of generating systems and their efficiency is shown at the left in Figure 1.[1-10] In comparison with gas turbine systems, SOFCs offer higher generating efficiency, as well as molten carbonate fuel cells (MCFCs), polymer electrolyte fuel cells

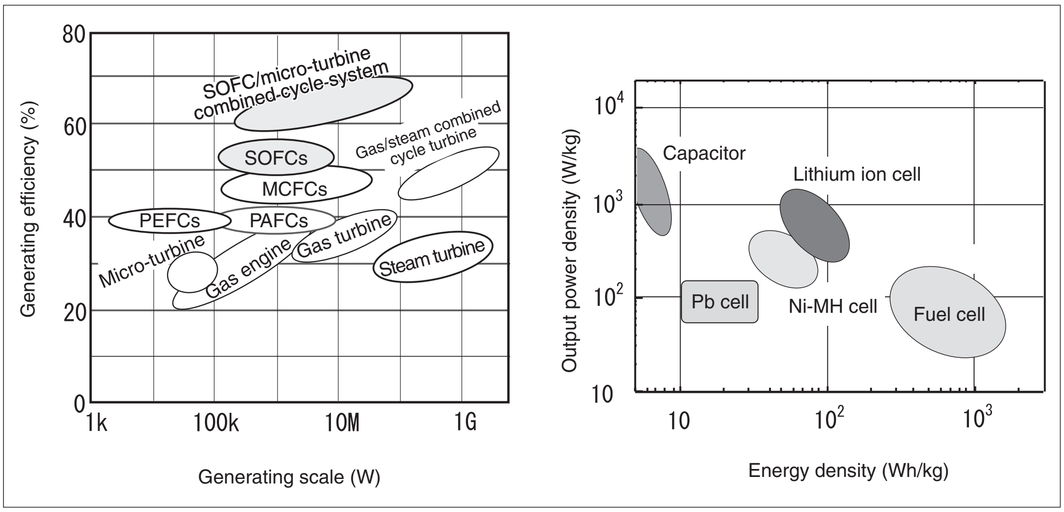


Figure 1 : Current efficiency of various power systems and comparison of the output power performance between various power generation systems

PAFC: Phosphate Acid Fuel Cells

Prepared by the STFC based on references [1-10].

(PEFCs), and others. Even higher total efficiency can be realized with an SOFCs combined cycle system (system combining an SOFCs system and a gas turbine), and when hydrogen is used as the fuel, the system discharges only water. Even when using a diverse range of fuels with higher energy densities, such as natural gas or coal gas, emissions of NOx and SOx are lower than systems with other fossil fuel systems. However, with the high temperature SOFCs developed to date, which have operating temperatures exceeding 750°C, heat control is difficult, in that long time is required for starting, etc. For this reason, only limited R&D has been carried out on portable systems which have a high start/stop frequency, and stationary systems have been the main focus of R&D.

As the most representative type of FCs except SOFCs, PEFCs are also an object of R&D. This type has a low operating temperature of 80°C-100°C, enabling easy handling, and because the system is compact, practical application as a power source for moving objects is progressing. However, PEFCs have the disadvantage of high cost because platinum catalysis or the catalysis carrying carbon and fluorine resin mixtures, etc. are used. Among other problems, if a reformed gas other than hydrogen is used as the fuel, cell performance tends to deteriorate due to exposure of the platinum catalyst of the electrode to carbon monoxide, and the performance of the electrolyte film itself may be reduced by long-term operation.

A comparison of the relationship between the unit energy density (Wh/kg) and unit output density (W/kg) of various FCs (SOFCs, PEFCs, MCFCs, PAFCs) and other types of cells is shown in Figure 1 at the right. At the current stage, FCs output density is still inferior to that of Li ion cells, but FCs have the advantages of high energy density and quick fuel replenishment. Thus, the challenge for the immediate future is to improve FCs output power density. Currently, application development is progressing in fields where electrical energy is required for extended periods of time, taking advantage of the feature of high energy density.

2-2 Promising fields for application of SOFCs

Promising fields for application of SOFCs are shown in Table 1, classified by the mode of the power source in uses and main applications. A diverse range of applications is expected for SOFCs, from micro systems to medium- and large-scale systems. In particular, high expectations are placed on distributed power sources, stationary power sources, and cogeneration systems (simultaneous supply of power and heat or hot water), especially in Europe and North America. Furthermore, steady progress is being made in application development for a home power source, auxiliary power supply for automobiles, and portable power source for mobile electronic devices and the like as well as for an alternative system for conventional power. In particular,

Table 1 : Fields of application for SOFC systems and main issues for the applications

System scale		Purpose Mode of use	Main application	Main issue	
Ultra-small scale	<1kW	Main power source On-board system Stationary	Robots Computer servers Mobile devices	Improvement of output power density Maintaining long-term performance High reliability Cost reduction (material, manufacturing process)	Compact size Low temperature operation Following load change
Small scale	1~100kW	Moving object (on-site) Stationary Cogeneration Automobile	Home use Automobile auxiliary power unit Electric vehicle Unmanned telecom base Charging device		
Medium-to-large scale	>100kW	Installed system Main system Cogeneration Emergency use	Ship Factory Commercial equipment Hospital		Medium temperature operation

Prepared by the STFC.

SOFCs is superior to competing technologies. As markets that take advantage of the distinctive features of SOFCs, cogeneration systems which operate steadily at a low capacity of 10kW or less for household and commercial service are considered important. If an economical fuel can be used, it is assumed that these systems will be introduced in commercial markets at an early date.[10-12]

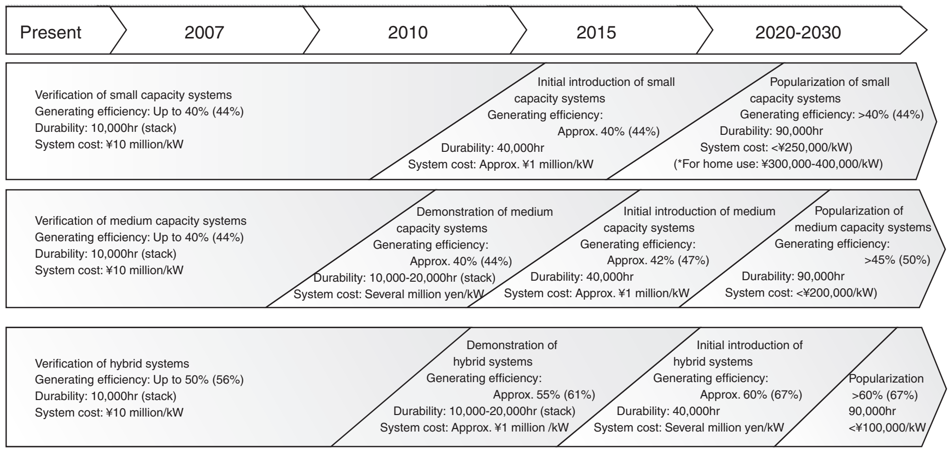
With regard to the conditions surrounding the introduction of SOFCs in Japan, it is generally thought that introduction as a distributed power source for household service, which is outside the scope of power industry liberalization, is more advantageous than constant load operation as a distributed power source for medium- to large-scale power generation. Due to their high generating efficiency, SOFCs are expected to have market potential even when limited to power generation outside the cogeneration field (i.e., without assuming heat generation). In the initial stage of SOFCs commercialization, it is generally thought that the first priority will be system reliability rather that cost, and introduction will be possible even at a system cost of ¥200,000/kW or less.[10] SOFCs auxiliary power units (APU) for moving objects have been studied at outputs from the several kW class of automobiles to the several 100kW class for large-scale ships.[13-17] In particular, because APU are used for steady loads, the number of starts and stops is small and quick starting time is not required. From this viewpoint, application of SOFCs is considered feasible.

3 Current status of R&D on SOFCs systems

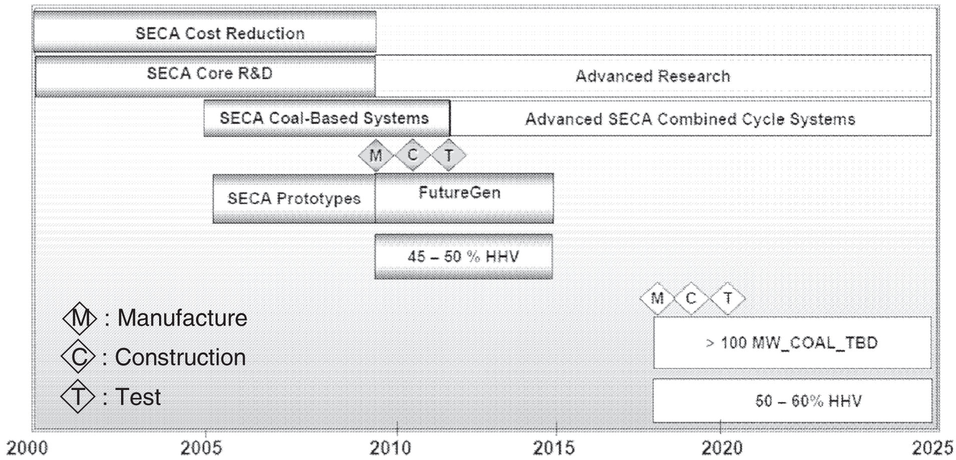
3-1 Status of R&D on SOFCs in Japan and other countries

Figure 2 shows the roadmap for the technical development of stationary SOFCs in Japan prepared by the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO), and the roadmap for the development of SOFCs systems in the Solid State Energy Conversion Alliance (SECA) project of the Department of Energy in the United States.[18-21]

In Japan, R&D on SOFCs began in fiscal year 1981 under the Moonlight Plan. As subsequent NEDO projects, R&D proceeded under Phase I (1989-1991), which focused on cell stack assemblies of several 100W class, Phase II (1992-2000), which prioritized cost reduction and reliability in cylindrical and flat-type SOFCs, and Phase III (2001-2004), which continued R&D on practical SOFCs systems (10+ kW class). The R&D issues for practical application of SOFCs in Phase III included improved cell performance, high output, cost reduction, and high reliability.[10] Concretely, in order to secure the high reliability and cost competitiveness necessary for full-scale commercial introduction of SOFCs, the mechanism of deterioration of cells and stacks under long-term service conditions was elucidated and countermeasures were proposed, costs were reduced by downsizing,



(a) Roadmap for technical development on SOFCs for stationary applications in Japan (source: NEDO)



(b) SOFCs development plan in US SECA Project (source: US DOE)

Figure 2 : Roadmaps for SOFC system R&D projects in Japan and US

Prepared by the STFC based on references [18-21].

which was enabled by realizing high output, and element technologies were developed, including technologies for responding to various types of fuels and operating conditions.[18,19] Figure 2(a) summarizes future technical issues in connection with stationary SOFCs systems and the expected timing of realizing those technologies over a timeframe extending to around 2020.[18] In particular, from 2004 onward, the priority is attached to technologies for improved reliability and stack technologies for the popularization period, based on a strong presumption that SOFCs will in fact be introduced and popularized. Especially with regard to systems from small-scale distributed power systems to medium-scale thermal power generation substitute systems with high operating temperature of around 950°C, the priority is assigned to the development of systems with an awareness of commercialization and confirmation of performance by operational demonstration.[22,23] In parallel with this, the R&D has already been begun on small- and medium-scale systems with medium-range operating temperatures of 700°C-800°C.[4]

At present, however, the most representative SOFCs R&D project from the global perspective is the SECA Project of the US Department of Energy, which can also be considered the most advanced project. In the United States, development of FCs for use in the electric industry began as the DOE's Vision 21 Program. Subsequently, the SECA Project was launched in 1999, and a strong cooperative system with industry, university, and government organizations was created. At present, the SECA Project is being implemented with all operations carried out by the National Energy Technology Laboratory (NETL). As targets, a low cost technology and technologies related to high performance and high reliability are to be established by 2010. A system with 45-50% HHV efficiency (higher heating value; a standard that considers the latent heat of water vaporization) is to be developed using coal gas, natural gas, or similar fuels, and a cost target of US$400/kW is to be achieved by around 2015.[13-17, 20, 21]

In both the United States and Japan, commercialization of SOFCs has not progressed as originally hoped, but nevertheless, the impetus toward practical application is accelerating through confirmation tests and other activities. In both countries, intensive confirmation tests are being conducted with the aims of maintaining power generating performance over the long term, reducing costs, and achieving high reliability, as these are the key issues for practical application, and confirming the effectiveness of the related measures. Furthermore, after confirmation of long-term generating performance and high reliability, both countries plan to introduce this technology in the market beginning with high temperature (operation at 750°C-1,000°C) medium- and large-scale systems.

Private-sector R&D is also being carried out independently of these government projects. Representative examples of recent R&D in the private sector in Japan include the following.[24]

- A prototype of a SOFCs system operating at 500°C using cells developed by Toho Gas Co., Ltd. and the National Institute of Advanced Industrial Science and Technology (AIST) was produced on a trial basis, targeting practical application of stationary systems for home and commercial use around 2012.
- Osaka Gas Co., Ltd. is jointly developing a SOFCs cogeneration system for household use with Kyocera Corporation, with commercialization scheduled for fiscal year 2008 or thereafter.
- The Central Research Institute of Electric Power Industry (CRIEPI), in joint work with AIST, is currently developing a SOFCs system for household use with an operating temperature of 500°C-650°C, and has achieved generating efficiency on a practical level with a prototype system.

3-2 Operating principle of SOFCs

SOFCs include the oxygen ion conduction type and the hydrogen ion conduction type. Figure 3 shows schematic diagrams of the operating principles of these SOFCs. As shown on the left, in an oxygen ion conduction type SOFC, oxygen ions are conducted through the electrolyte and combine with hydrogen at the fuel electrode, forming water. Power is produced between the electrodes when electrons are discharged in the water formation process.

On the other hand, as shown at the right in Figure 3, in the hydrogen ion conduction type SOFC, electrons are discharged when hydrogen ions form at the fuel electrode, and power is produced between the electrodes when these

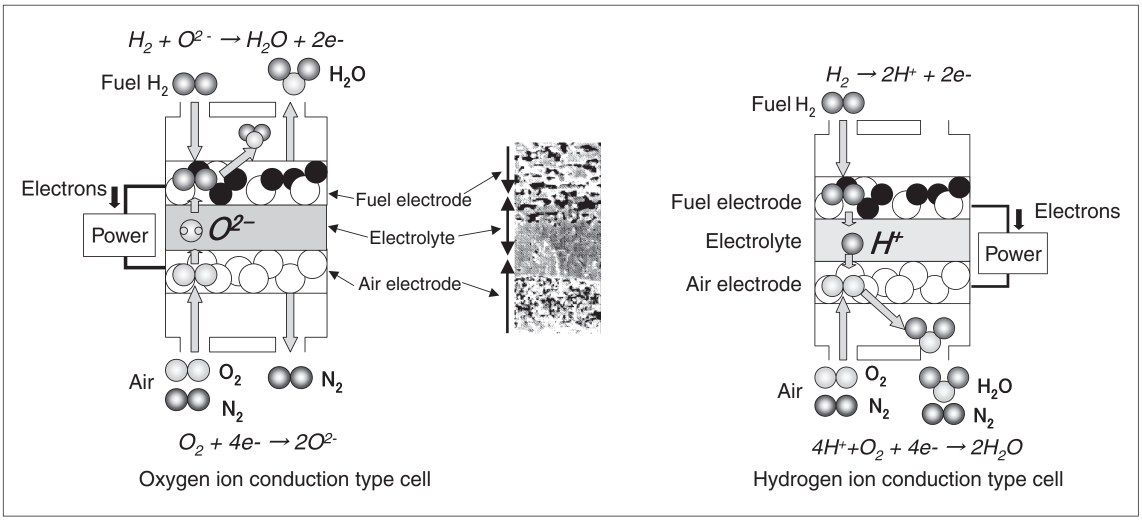


Figure 3 : Operating principles on hydrogen and oxygen ion conduction type SOFCs (schematic diagrams of two-chamber SOFCs)

Prepared by the STFC.

hydrogen ions pass through the electrolyte.[25-27] Because only chemically unstable hydrogen ion conducting electrolytes have been discovered to date, little work has been done on this type of electrolyte. Virtually all R&D has involved SOFCs which utilize an oxygen ion conductor.

Figure 3 showed the operating principle of the two-chamber SOFC. In this type, the fuel and air are supplied to separate chambers. The fuel electrode and air electrode are positioned in the respective chambers and are connected via the electrolyte. In the single-chamber SOFCs, a mixed gas of fuel and air is supplied to a single chamber. When the electrolyte is an oxygen ion conductor, oxygen ions are generated from the air electrode in the mixed gas. These ions are conducted through the electrolyte and react with hydrogen at the fuel electrode, producing an electromotive force between the two electrodes. Because the fuel and air are not separated in the single-chamber SOFCs, research reports have pointed out that this type is superior in various respects, in that a more compact design is possible in comparison with the two-chamber type, mechanical strength and durability are easily secured in the system as the structure does not include a separator, and quick starting is achieved as a result of heat generation at the electrodes.[28-32] As disadvantages, single-chamber systems are prone to direct oxidation of the air and fuel, and no electrolyte with high ionic conductivity comparable to that used in two-chamber systems has yet been discovered. For these reasons, R&D is overwhelmingly concentrated on the two-chamber type at present. However, assuming the above-mentioned problems can be overcome in the future, the single-chamber type is considered to offer many advantages, particularly in small-scale systems.

3-3 SOFCs stack structure

The cell structure of two-chamber SOFCs systems is categorized as cylindrical or flat. In the cylindrical type, the contact area at the interface between the electrolyte and electrodes is small and as a result, the current path in each cell is long and Joule loss is large. In view of this drawback, R&D on small- and medium-scale systems has focused mainly on the flat type. Figure 4 shows a schematic diagram of a flat stack system and an example of a stack.[33] In order to obtain high output, the stacks are constructed by connecting single cells in series. The separator where the cells are connected in series performs the functions of transmitting electrons and separating the fuel gas and air. To obtain a satisfactory electrical connection, contact at the interface between the electrolyte and the electrodes is important, while control of the porosity of electrode material is critical for securing the flows of fuel and air at the respective electrodes. Moreover, the electrolyte and the separators must possess sufficient density to prevent mixing of the two gases.

The following will describe the current status and issues in R&D on electrolytes, which have the greatest effect on SOFCs generating performance, as well as possible solutions, for oxygen ion conductors in two-chamber SOFCs, which are currently the main stream in R&D.

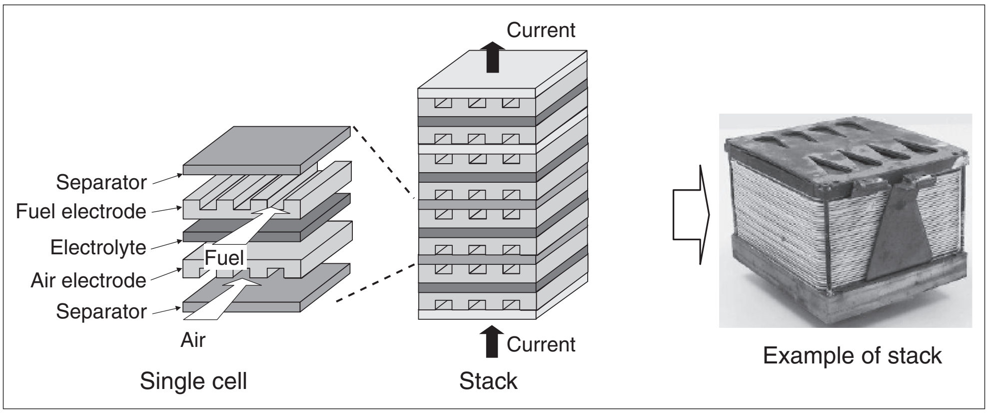


Figure 4 : Simplified schematic diagram of flat stack system and an example of a stack

The photograph of the stack at the right was reproduced from reference [33].

Table 2 : Typical component materials of SOFCs cells developed to date

Component part	Main material	
Electrolyte	Stabilized zirconia type Cerate type Lanthanum gallate type	YSZ: Y_2O_3 stabilized ZrO_2 SSZ: Sc_2O_3 stabilized ZrO_2 Sm_2O_3 doped CeO_2 (La, Sr) (GaMg) O_3
Fuel electrode	Ni/YSZ cermet, Ru/YSZ cermet	
Air electrode	$LaMnO_3$ type $LaCoO_3$ type	(La, Sr) MnO_3, (La, Ca) MnO_3 (La, Sr) CoO_3, (La, Ca) CoO_3
Separator	$LaCrO_3$ type Alloy type	(La, Sr) CrO_3, (La, Ca) CrO_3 Ni-Cr type, ferrite (Fe) type

Prepared by the STFC.

4 Current status and issues in electrolyte R&D

4-1 Current status of electrolyte R&D

SOFCs efficiency improves as the ionic conductivity of the electrolyte used increases. This is explained by the fact that, in many cases, virtually all of the internal resistance in a cell is attributable to electrical resistance loss caused by resistance in the electrolyte. Table 2 shows representative component materials of the SOFCs cells which have been studied to date, classified as electrolytes, electrode materials, and separator materials. [1, 25-27] In high temperature (750°C-1000°C) SOFCs, much research has been done on yttria-stabilized zirconia (YSZ: Y_2O_3 stabilized ZrO_2) as the electrolyte, nickel-zirconia (Ni-ZrO_2) cermet as the fuel electrode material, lanthanum manganite ($LaMnO_3$) as the air electrode material, and lanthanum chromite ($LaCrO_3$) as the separator. However, materials with high oxygen ion conduction, such as scandia-stabilized zirconia (SSZ: Sc_2O_3 stabilized ZrO_2), lanthanum gallate ($LaGaO_3$), and others, have been the object of intensive research as non-YSZ electrolytes in recent years. In addition to these electrolytes, R&D is also being done on various hydrogen ion conductors, such as barium cerate (barium cerium oxide; $BaCeO_3$), strontium cerate ($SrCeO_3$), and related materials. Nevertheless, in terms of ion conduction characteristics, chemical stability, cost, and the number of examples of R&D, even today YSZ continues to be the most important electrolyte. SSZ and $LaGaO_3$ are promising materials for application as electrolytes for medium temperature SOFCs operating at 750°C and under. YSZ, the cerate based electrolytes, and $LaGaO_3$ reveal increasingly high oxygen ionic conductivity in that order.

4-2 Features required in electrolytes and the related issues

As conditions for commercialization, SOFCs must possess power generating characteristics and long-term reliability equal or superior to those of competing generating technologies, and their cost must be no higher than that of other technologies. Table 3 shows the main properties required for electrolytes, as well as those of other SOFCs component materials.[10,26,27,34]

Table 3 : Main properties required for SOFCs component materials

Component part	Required properties
Electrolyte	High ionic conductivity, Long-term high temperature performance stability, Density, High long-term reliability (high strength, high durability)
Fuel electrode	Large reaction field (water formation), Numerous paths for electron and ion conduction, Appropriate porosity (smooth migration of hydrogen and formed water), High temperature stability
Air electrode	Large reaction field (oxygen absorption, ionization), Numerous paths for electron and ion conduction, Appropriate porosity (oxygen migration), High temperature stability
Separator	Density, Electron conductivity, High temperature/chemical stability
Cell stack	Sealability (gas shielding between electrodes), Strong bonding between materials and absorption of differences in thermal expansion, Low reactivity between component parts

Prepared by the STFC.

When designing a cell, first, an electrolyte that demonstrates high ionic conductivity at the operating temperature is decided. This is followed by selection of fuel and air electrode materials capable of extracting the maximum performance from the electrolyte. Therefore, if the electrolyte is not decided, the cell, stack, and SOFCs system structure cannot be materialized. In order to secure reliability, in other words, to secure high performance over an extended period of time, a variety of issues arise in connection with the selection and combination of the electrolyte and electrode materials, the process of manufacturing parts from these materials, the multilayer cell structure, system design, techniques for evaluating performance and durability/reliability, and so on. These issues are discussed below under the headings of generating performance, system structure, and the manufacturing process.

(1) High generating performance and long-term performance stability

When using hydrocarbon fuels, it is necessary to set the reaction temperature of the fuel so as to prevent carbon precipitation and thereby avoid performance deterioration. In order to maintain the original performance of the FCs and minimize performance deterioration over time, it is important to select a combination of materials, including the electrolyte and electrode materials, which is suitable for service environment conditions, including the operating temperature.

There is a possibility that all of the problems of maintaining long-term generating performance, securing high reliability, and the like can be solved at once by reducing the operating temperature. To achieve this, it will be necessary to discover a new electrolyte which has low electrical resistance, in other words, an electrolyte with high ionic conductivity, in the low temperature region.

(2) High strength/reliability system structure

Because the thermal expansion coefficient of electrodes and electrolyte will differ in most cases, the deformation and the damage of cells at operating temperature are problems. The difference in the thermal expansion of the electrolyte and electrodes during the temperature rise from room temperature in a static condition to the FCs operating temperature can easily cause deformation and cracks, either internally in the electrolyte and the electrodes, or at the interface between the two materials. For this reason, structural strength design capable of preventing these problems is indispensable in the cells and the stacks.

Long-term stability of the joints between the separators and cells is also a problem. A fuel cells stack is a multilayered structure comprising layer-shaped components of heterogeneous ceramics. It is therefore important to establish cells and stack structural designs which guarantee durability and reliability in long-term operation by preventing the crack initiation and propagation in and between these layers, and manufacturing processes for realizing these designs.

(3) Low cost manufacturing process

The cost of high temperature systems which are now in the confirmation test stage cannot still be considered competitive with other power generating systems. In order to reduce the cost of cells and stacks, it will be necessary to minimize the use of expensive materials, simplify the manufacturing process, and establish manufacturing methods suitable for mass production. As the electrolyte and electrode materials are ceramics, various technical issues must be solved in connection with the preparation of the ceramic raw material powders and the powder slurry and the subsequent molding and the sintering process as manufacturing processes peculiar to ceramics.[35] In forming thin films of the electrolyte, gas phase methods such as pulsed-laser deposition (PLD) can be used in the laboratory, but when considering mass production in the future, a wet process film-forming technology such as the tape casting method is desired.

5 Solutions to electrolyte-related issues

5-1 Necessity of elucidating the ion conduction mechanism in the electrolyte

In order to maintain the generating

performance of SOFCs systems over the long term, it is necessary to investigate the mechanism which controls performance deterioration in cell component materials. In this, it is important to investigate the ion and electron conduction mechanisms as far back to the nano region of the electrolyte. The following describes an elucidation of the ion conduction mechanism in the electrolyte and the ion conduction mechanism in the interfacial region between the electrolyte and electrodes, and a method of analyzing their behavior in the nano region.

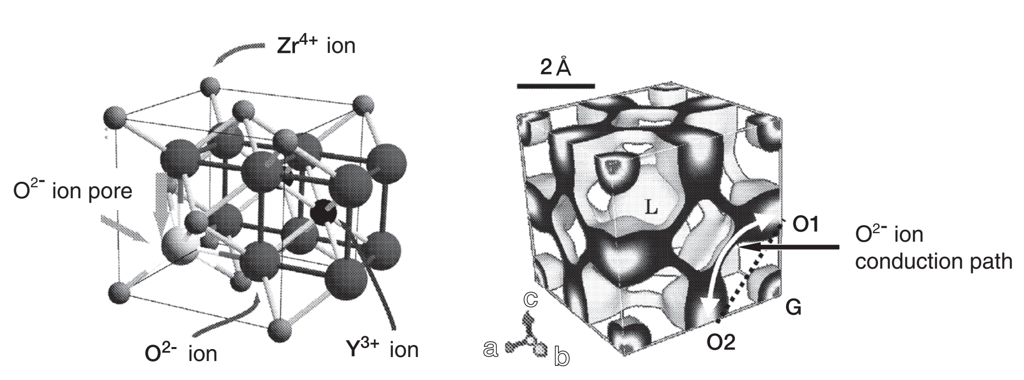
(1) Elucidation of the ion conduction mechanism in the electrolyte

In solid oxides such as YSZ which comprise a crystal structure with numerous oxygen defects, high ion conduction occurs as a result of exchange of the positions of defects and ions. One class of materials which is capable of maintaining a stable crystal structure even though a large number of defects occur is the perovskite oxides*1.[36] With this type of crystal structure, when oxygen ionic conductivity increases, oxygen desorbs easily from the lattice and the material readily manifests electronic conduction, resulting in problems of reduced performance in extended high temperature operation and deterioration due to aging. However, these behaviors are known empirically. The ion conduction mechanism originating in the compound structure of defects at the nanoscale should be investigated while also verifying the phenomena concerned experimentally. Elucidation of these points will make it possible to control the nanostructure of the electrolyte.

Figure 5(a) shows an example of an analysis of the mechanism on ion conduction in YSZ by the laser emission spectrum method;[37] Figure 5(b) is an example of analysis on the ion conduction path of an $LaGaO_3$ based compound by the high temperature neutron diffraction method.[38] Figure 5(a) is an example in which the mechanism on oxygen ion (O_2-) conduction in YSZ was elucidated, showing a schematic diagram of ion conduction in which an O_2- ion occupies a defect as an O_2- ion hole. Figure 5(b) shows conduction in a crystal, in which O2- ions in an $LaGaO_3$ based compound are distributed continuously and widely in the vertical direction in an arc shape between the stable positions O1 and O2, and the O_2- ions maintain bonds with and rotate around cations (positive ions) of a compound of gallium, magnesium, and cobalt ($Ga_{0.8}Mg_{0.15}Co_{0.05}$). It may also be noted that the results of the analysis on O_2- ion conduction by this high temperature neutron diffraction method showed good agreement with the results of an analysis by the molecular dynamics method.

(2) Elucidation of the ion conduction mechanism in the interfacial region between the electrolyte and electrodes

Together with the ionic conductivity of the electrolyte itself, that in the boundary region between the electrolyte and the electrodes also



(a) Schematic diagram on the O^{2-} ion conduction mechanism in YSZ as analyzed by the laser emission spectrum method

(b) Conduction paths and spatial distribution of O^{2-} ions in an $LaGaO_3$ compound

Figure 5 : Example of analysis on the oxygen ion conduction mechanisms in YSZ and a LaGaO3 based compound

Prepared by the STFC based on references [37] and [38].

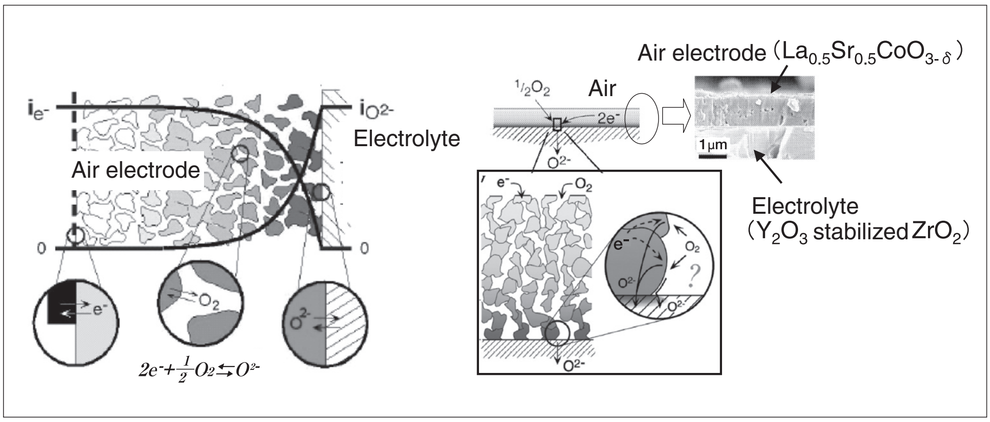


Figure 6 : Schematic diagram on the mechanism of ion conduction in the boundary region between the electrolyte and the air electrode

Prepared by the STFC based on references [39] and [40].

controls the generating performance of SOFCs. Research to elucidate the mechanism of this type of ion conduction was begun recently. Figure 6 shows a schematic diagram on the mechanism of ion conduction in the interfacial region between the electrolyte and the air electrode.[39,40] This chart is a model for elucidating the influence of oxygen ion and electron conduction in the interfacial region between the electrolyte and the electrode, the mixed conduction paths of oxygen ions and electrons, and the mechanism involved on the voltage-current characteristics of the FCs. Clarification of the electrochemical behavior on ions and electrons at the interface between the electrolyte and the electrode would provide research guidelines for determining favorable nano- to micro- scale structures in the electrolyte-electrode interfacial region. The DOE's SECA Project is engaged in an analysis of the relationship between electrochemical behavior and material structure in collaborative work by universities and national research institutes.[39,40] Clarification of the mechanism on the electrochemical reaction in the electrolyte-electrode interfacial region will also contribute to strengthening basic evaluation techniques for SOFCs.

(3) Analytical method for ion conduction behavior in the nano region of the electrolyte

It can be said that to date R&D on cell structural materials, including electrolytes, has been carried out by repeated trial manufacture and evaluation of the materials. However, in the development of materials which manifest revolutionary properties, elucidation of the mechanism responsible for those properties in the nano scale region offers a shorter route than this type of trial-and-error R&D. In other words, an ever-increasing number of examples demonstrate the possibility of realizing dramatic improvement in material properties by the various methodologies for theoretical calculation and experimental verification referred to as nano materials science. Likewise, in R&D on SOFCs electrolytes, it is indispensable to elucidate the atomic and electronic structure by simulations using quantum theory, obtain guiding principles through integrated use of theoretical calculations and experiments, and horizontally systematize various types of materials based on their atomic and electronic structures. Theoretically-based simulation techniques include first-principles calculations, the molecular orbital method, and the molecular dynamics method, while experimental techniques for elucidation of nanostructures include the neutron diffraction method, laser Raman spectroscopy, high resolution transmission electron microscopy (HR-TEM), and electron energy loss spectroscopy (EELS), among others. Figure 7 shows a schematic diagram on methods of creating novel materials by elucidating the mechanism responsible for functions in the nano scale region.

In the future, it will be desirable to carry out research to discover new electrolytes by clarifying the mechanism responsible for material functions through mutual use of empirical and simulation techniques, and to carry out theory-led R&D based on the mechanisms elucidated in this

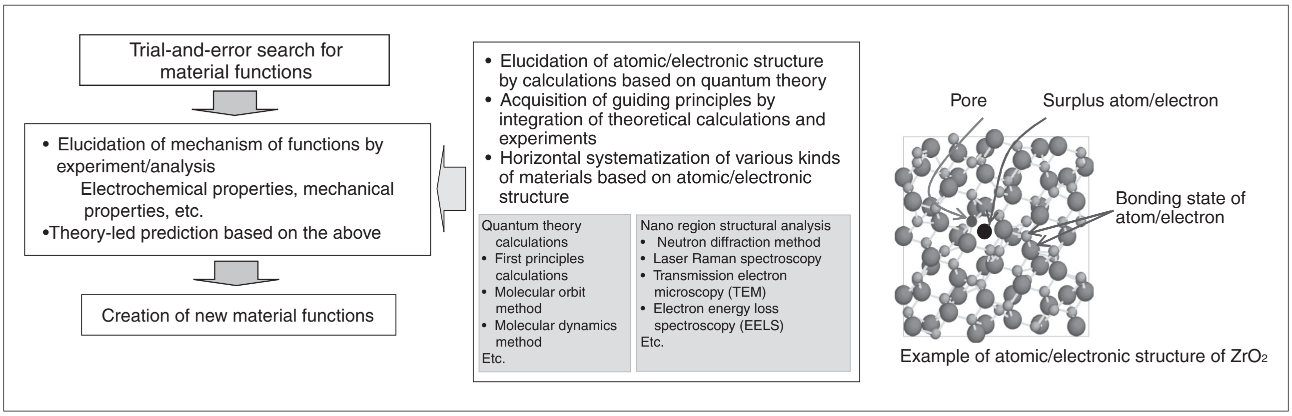


Figure 7 : New material creation method based on elucidation of the mechanism responsible for functions in the nano scale region

Prepared by the STFC.

manner.

5-2 Elucidation of mechanism on electrolyte damage/deterioration

One current issue in R&D on medium- and high temperature SOFCs in Japan shown in the roadmap in Figure 2(a) is technologies for improving reliability under operating environment conditions. Where this is concerned, it is necessary to investigate the mechanism which controls the damage/deterioration behavior of electrolytes from the macro to the nano scale region. It is considered possible to shorten R&D time as a whole by a procedure of assigning priority to elucidation of the mechanism and actually constructing the system in the final stage, rather than by attempting to achieve R&D targets through a time-consuming process of repeated trial manufacture and evaluation of the system. Analysis of behavior in the nano scale region, which was described in section 5-1 is an effective tool for this purpose.

Analysis of stack destruction behavior has become a top priority topic in the DOE's SECA Core Technology Program, and cell structure-related destruction criteria have been an object of intensive R&D up to the present.[21] Placing priority on elucidation of the electrochemical reaction in the electrolyte-electrode interfacial region and analyses of cell and stack destruction behavior, this program is investigating the behavior of materials down to the nano scale region and the related mechanisms, carrying out research on fundamental analytical techniques for these items, and developing simulations and analytical techniques for destruction behavior up to the macro scale.

Long system life is a precondition for SOFCs. However, in the case of medium and high temperature systems, full-scale confirmation tests of long-term performance stability are still in the future. Although development of medium temperature systems is continuing to progress, researchers have relatively little experience with the electrolytes used in these systems in comparison with those in high temperature systems. Therefore, intensive R&D to clarify the mechanical mechanism of defect formation and propagation and expansion of those defects from the nano to the macro scale based on the technologies accumulated with the high temperature type is expected. Elucidation of the mechanism on deterioration and establishment of methods for measuring material life, including materials other than the electrolyte, is indispensable.

5-3 Development of low cost manufacturing processes for cell component materials including electrolytes and low operating temperature systems

The approaches to reducing the cost of high temperature SOFCs systems are (1) adopting low cost electrolytes and other cell and stack component materials and (2) reviewing the manufacturing process for those materials and components. For this, it is necessary to understand the relationship between the electrochemical behavior and the mechanism by which properties are manifested in the electrolyte in the operating environment and the electrode materials which enable the electrolyte to manifest its properties fully, and the micro- and macrostructure of these materials at the mass production scale. This manufacturing process technology also includes the selection of low cost ceramic materials, manufacturing processes peculiar to ceramics, and related issues. In the material manufacturing process, wet ceramic processes such as the doctor blade method, spin coat method, and similar techniques are processes for manufacturing low cost ceramics. On the other hand, film manufacturing processes such as physical vapor deposition (PVD), chemical vapor deposition (CVD), pulsed-laser deposition (PLD), and colloidal spray deposition (CSD) are effective methods of film-forming in the material search stage, but are not suitable for mass production of practical cells and stacks. This means that is important to assume, from the first stage of research, an electrolyte film production method which is not limited to simply obtaining small sized samples, but will also enable production of large areas of material and mass production.

Until now, in the initial stage of R&D, R&D on high temperature SOFCs which operate at 750°C-1,000°C was the main stream, but for the above-mentioned goals of securing reliability, reducing cost, and shortening starting time, low temperature operation is desirable. Figure 8 shows the relationship between high reliability, low cost, and high performance, which are reasons why low temperature SOFCs are necessary, and cell component materials, beginning with the electrolyte. Low temperature operation makes it possible to produce low cost cells because heat insulation is easy, freedom of material selection is increased, metal separators can be used, and sealing of the cells and stack is simplified. As a result, a more compact design can be realized in the low temperature system as a whole in comparison with the high temperature type. In addition, high reliability can also be achieved because the temperature differential between the cells is reduced, and performance can be maintained over the long term because deterioration at the electrolyte-electrode interfacial region is prevented, and as a result, a stable reaction surface area can be secured.[22,35,36,41,42]

On the other hand, if the operating temperature is reduced, generating performance also decreases because electrolyte resistance increases and the reactions at the electrodes become inactive. More specifically, although the maximum theoretical efficiency of conversion from chemical energy to electrical energy increases as the operating temperature decreases, electrolyte resistance and reaction resistance in the electrode interfacial region also become greater, and consequently, generating efficiency is also reduced. This means it is necessary to develop electrolytes which display sufficiently low electrical resistance even at low temperatures.

5-4 Search for new low temperature electrolytes

Figure 9 shows schematically various types of electrolytes, including both inorganic materials (ceramics) and organic materials, from the viewpoint of ion and electron conductivity and

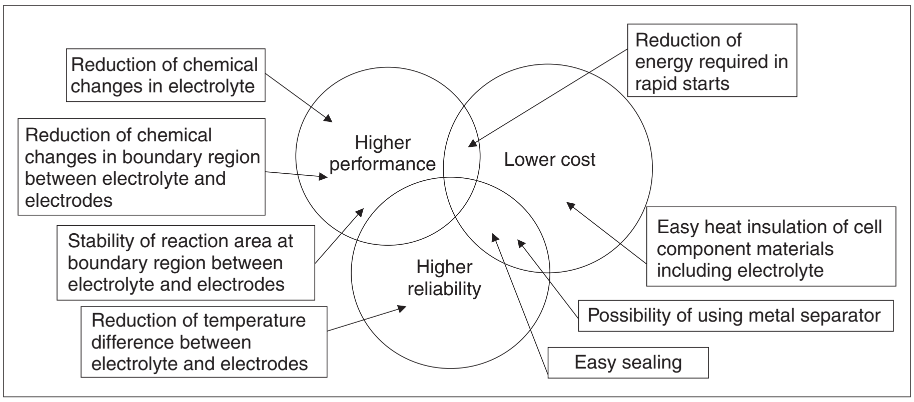


Figure 8 : component materials, focusing on the electrolyte

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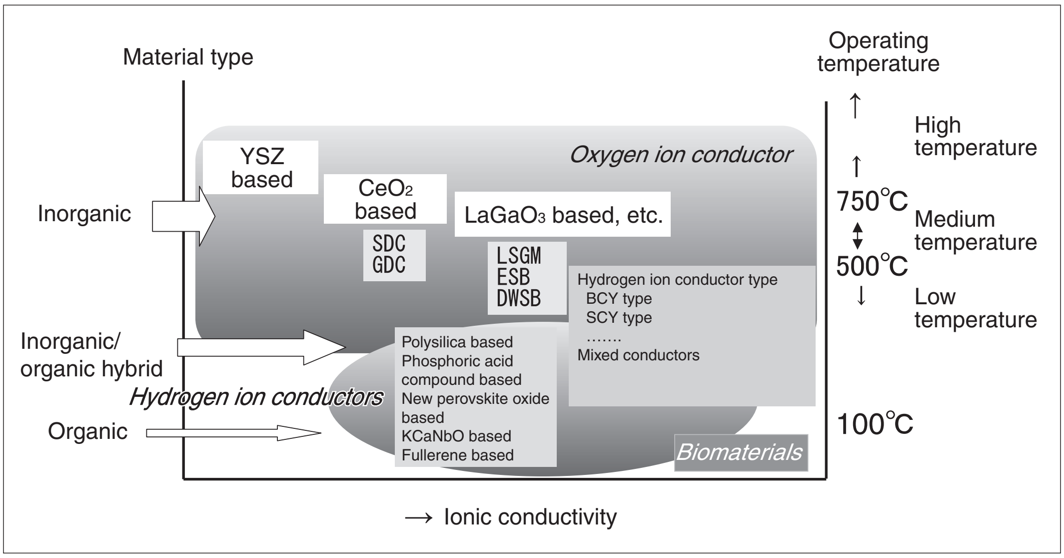

Figure 9 : Classification of electrolytes based on ion conductivity and operating temperature

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operating temperature. Because various problems have become apparent in high temperature operation, intense R&D on electrolytes for medium temperature operation as substitutes for YSZ has been underway since several years prior to this article. This work centers on cerate (CeO_2) based oxides (e.g., SDC: CexSm1-xOy) and $LaGaO_3$ based oxides. It may be noted that these $LaGaO_3$ based oxides are a class of high oxygen ion conductors which was developed at a university in Japan.[36]

R&D on electrolytes for low temperature operation based on these oxides has become active in recent years. Moreover, the search for electrolytes such as LSGM ($La_xSr_{1-x}Ga_yMg_{1-y}O_3$) which display high oxygen ionic conductivity at temperatures under 500°C has become even more active.[43,44] The oxides GDC ($Ce_xGd_{1-x}O_2$), ESB ($Bi_{2-x}Er_xO_3$), DWSB ($Bi_{2-(x+y)}Dy_xW_yO_3$), and others have also attracted attention as electrolytes which exhibit high ionic conductivity at low temperatures,[45] and it is possible that other electrolytes with dramatically higher ionic conductivity in low temperature operation may also be discovered.[42] Although new low temperature electrolytes with performance equal or superior to that of high temperature materials are still in the search stage, and system technologies which use these electrolytes are in the germinal stage, they have the potential to solve all of the problems confronting high temperature systems at once. Thus, if it proves difficult to solve the problems limiting the commercialization of high temperature systems, one option is to shift decisively to R&D on low temperature systems. This search for novel electrolytes should be carried out from both the theoretical and experimental directions using nano-level computer simulation and experimental verification techniques, taking advantage of the remarkable advances in nanotechnology in recent years.

Table 4 is a list of the necessary conditions for material design for SDC, GDC, LSGM, etc., which are the main electrolytes for low temperature operation announced in various journals and elsewhere to date. Realizing low polarization or low ohmic resistance by using a thin film electrolyte is an effective approach to improving low temperature oxygen ion conduction characteristics. However, what production process is to be used in producing these thin films is an issue.

At present, electrolytes for medium temperature operation are continuing to be established, and materials for low temperature operation are in the search stage. Determining the optimum electrode material for use with the respective electrolytes is an important technical element for the development of cells with high generating efficiency and high reliability. Figure 10 shows the relationship between electrode materials, types of fuels, operating temperature, and the structure at the cell to stack levels and

Table 4 : Necessary conditions in material design of low operating temperature electrolytes

Necessary condition in material design	Oxygen ion conductor			Hydrogen ion conductor
	SDC	GDC	LSGM	BCY
Ionic conductivity	○	○	○	◎
Insulation property	△ Under low oxygen partial pressure	△ Under low oxygen partial pressure	○	○
Chemical stability	○	○	△ Ni + SDC addition	—
Chemical stability (oxidizing/reducing atmospheres)	△	△	× Under low oxygen partial pressure	△ Pr addition
Gas shielding (nonporous)	○	○	△ ~○ PLD method	○ CSD method
Film uniformity (reduction of ohmic resistance)	△	○	△ ~○ PLD method	○ CSD method
Thermal expansion (same as electrodes)	○	○	○	—
Low cost	△	×	× ~△	○

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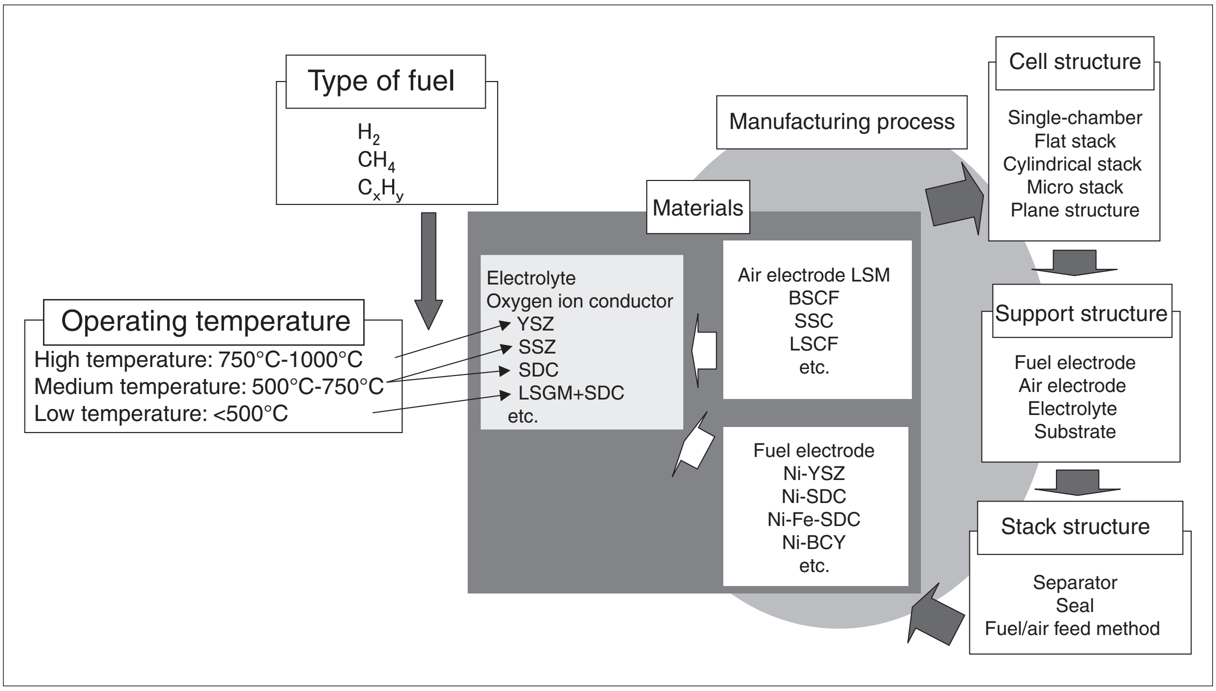

Figure 10 : Relationship between electrode materials, fuels, operating temperature, and cell and stack structure to electrolytes

LSM: $La_xSr_{1-x}MnO_3$
BSCF: $Ba_xSr_{1-x}Co_yFe_{1-y}O_3$
SSC: $Sm_xSr_{1-x}CoO_3$
LSCF: $La_{1-x}Sr_xFe_yCo_{1-y}O_3$

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the electrolytes developed to date. When an oxygen ion conducting electrolyte is used, the possible reduction in the operating temperature is wholly related to high ionic conductivity in the electrolyte at a low operating temperature and the selection of an electrode material which allows the electrolyte to fully demonstrate this characteristic. In other words, in addition to high conductivity in the electrolyte itself, the generating performance of SOFCs is also influenced by easy generation of oxygen ions at the air electrode and their conduction to the electrolyte, high efficiency transfer in the fuel electrode interfacial region, and the electrochemical reaction with hydrogen.

6 Directions in industry-cademia-government collaboration on SOFCs R&D in Japan

Globally, R&D on high temperature SOFCs has reached a stage where wide-ranging confirmation tests of SOFCs systems are underway. Several years ago, it had been predicted that these devices were nearing commercialization, but at present, no SOFCs system is actually being sold commercially in any country. This is due to the failure to solve various problems, including the fact that system reliability cannot be confirmed and cost has not yet reached a level where SOFCs systems can compete with other technologies. Improvement or development of new materials for cells and stacks, beginning with electrolytes, through collaboration among industry, academia, and government in their respective fields of expertise is desired in order to overcome these problems.

One target in the Nanotechnology & Materials area of Japan's 3rd Science and Technology Basic Plan is the development of innovative FCs materials for the purpose of achieving a large increase in energy utilization efficiency through technical innovation.[47] This is currently in the basic stage and will require considerable time to reach practical application. For R&D which strongly has a social nature and an important impact on environmental protection, it is necessary to develop a new R&D process which frees itself from the methods used in projects in the past and induces innovation by collaboration among industry, academia, and government organizations. In realizing SOFCs which meet the requirements of improved generating characteristics, long-term performance, and reliability in diverse service environments, clarification of the mechanism responsible for functions in the nano scale region of cells component materials is indispensable, centering on electrolytes. The creation of innovative SOFCs should be pursued through collaborative research by industry, academia, and government which prioritizes this type of fundamental and basic technology. In this, universities and R&D Independent Administrative Institutes (IAI) are expected to play a large role in fundamental research. To fulfill these expectations, further improvement and expansion of fundamental research at universities and IAI are needed.

METI's "New Economic Growth Strategy" proposes commercialization and market development through cross-sectoral integration and collaboration in industry, academic, and governmental R&D, which has been carried out independently to date, and suggests a paradigm shift, for example, by returning to basic science as a key point for successful innovation.[48] In particular, in cases where R&D appears to be blocked, breakthroughs should be realized by temporarily suspending work which is simply a linear extension of the existing R&D and carrying out R&D that return to fundamental scientific principles.

In future national projects related to SOFCs in Japan, a complete strategic study should be made even in the stage before research topics are selected, and these projects should aim at achieving the world's top results when setting target values. In the present context, this means R&D aimed at realizing the world's top SOFCs generating performance. A key part of any effort to develop innovative SOFCs systems must be research that returns to the basic science by elucidating the mechanism responsible for the properties of the cell component materials, and particularly the electrolyte, and R&D on the analytical techniques required to support that research. In this, smoothly linking material technology "seeds," in other words, the results of fundamental research based on materials science by universities and R&D IAIs, and the "needs" of technical development by industry on the system side will be decisive for the creation of innovative technologies.

7 Conclusion

Reasons for the strong interest in SOFCs among the various types of fuel cell systems were discussed from the viewpoint of their features as a high efficiency power generating technology, fields in which application is expected, and the current status of R&D in Japan and other countries. In particular, current issues related to SOFCs generating systems were examined from the viewpoint of electrolytes, and methods of solving these problems in the future were proposed.

High temperature SOFCs are now in the confirmation test stage. However, problems related to (1) long-term generating performance, (2) cost reduction, and (3) reliability must be solved in order to achieve practical application. To solve these problems, an elucidation of the mechanism on performance deterioration in cell component materials reaching back to the nano scale region of the materials will be necessary. R&D related to the analytical techniques required to support this type of research are also essential. To secure reliability, in addition to an empirical elucidation of the mechanism on deterioration in component materials, R&D which effectively utilize computer simulation techniques for damage/deterioration are also desirable, particularly from the viewpoint of research efficiency. To reduce the cost of SOFCs systems, it is necessary to adopt economical cells and stack materials and review the manufacturing processes for these materials. It is also important to understand the relationship between the micro- and macroscopic structures of cells component materials in the trial manufacture stage and the structures of same materials at the mass production scale from the viewpoint of the electrochemical behavior in the cell component materials, including the electrolyte, and the mechanism responsible for their properties.

On the other hand, in recent years, electrolytes such as scandia-stabilized zirconia and lanthanum gallate, which display high oxygen ionic conductivity even at low temperature (500°C-750°C and under) have been the object of intensive R&D as alternatives to yttria-stabilized zirconia (YSZ), which is used in high temperature SOFCs. Although R&D on these novel electrolytes and SOFCs systems is still in the germinal stage, these technologies have the potential to solve all of the problems confronting high temperature systems at once.

If the problems limiting commercialization of high temperature system cannot be solved through the current R&D, one option is a decisive shift to R&D on low temperature systems. Considering the remarkable progress which has been achieved in nanotechnology in recent years, the search for new electrolytes for these systems should include both theoretical and empirical approaches, taking advantage of computer simulation and experimental techniques at the nano scale level. It is also important to carry out R&D on materials suitable for cell and stack manufacturing processes, envisioning the practical SOFCs systems of the future, from the material search stage. Moreover, in developing systems which use these new electrolytes, a paradigm shift from the trial-and-error approach used to date to a science-based methodology is desirable. That is, it is important to carry out R&D while clarifying the behavior by which materials manifest properties in the nanostructural region, rather than prioritizing the conventional process for repeated trial manufacture of prototype systems and measurement of their generating characteristics. Finally, in many areas of this R&D work, an approach based on fundamental research by universities and R&D IAI and management methods which effectively enable collaboration among industry, academia, and government and implement an appropriate division of work, can be expected to yield important results.

Glossary

*1 A class of oxide ceramics expressed by a compound of oxygen and metal elements A and B (ABO_3). Virtually all of the metallic elements in the Periodic Table are possible component elements. Depending on the combination of A and B, perovskite oxides reveal a variety of properties, including ferroelectric properties, superconductivity, and ionic conductivity.

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5

Proposals for Research and Development on Monodzukuri (Manufacturing) Measurement Supporting the Competitiveness of Japanese Manufacturing Industries

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1 Introduction

Japan's manufacturing industries are the driving force supporting the economic growth of the nation. Japan has succeeded in producing products of the highest quality and reliability because outstanding engineers and technicians at the manufacturing site understand design concepts and are able to feed back site information on manufacturing to the design process.[1] Advanced techniques are cultivated and transmitted to younger employees in unified efforts extending from product design to actual manufacturing. Japanese manufacturing industries have long enjoyed a position of international superiority, but are now exposed to intense competition not only from the traditional industrial nations of Europe and North America, but also from a wide range of other countries.[1-3] As one background factor, although Japan was once considered simply a source of labor, its manufacturing industries steadily improved their technical capabilities, making the country a base for the production of high quality, high value-added products. However, the possibility that the superiority of Japanese manufacturing technology, or monodzukuri may be challenged in the near future is undeniable.

Given these circumstances, Japan's manufacturing industries must create new products which have an impact on world markets, achieve significant innovations in design and manufacturing processes, and dramatically improve product reliability in order to maintain and enhance their international superiority. For this, strengthening of monodzukuri backed by science and technology is necessary. The "White Paper on Monodzukuri 2006" presented the results of questionnaires completed by 300 listed companies as "Issues and Outlook for Japan as a Base of Innovation in Manufacturing Industries." More than half of the companies replying mentioned "The necessity of scientific knowledge in technical development is increasing annually.[3] In the strategy for promoting the "Monodzukuri Technology field" in the Third Science & Technology Basic Plan,[4] "monodzukuri" is defined as "value creation-type manufacturing" which aims at the development of science and technology so as to enhance the value of products (mono).[1] In the strategy for this field, "Reconstruction of science-based Japanese-style manufacturing" is mentioned as a basic policy.[1]

In monodzukuri measurement, various physical quantities related to product performance and manufacturing processes are digitized, and the results of data analysis are explained in scientific/technical terms. Thus, from the viewpoint of science-based manufacturing, it is one key element for promoting this policy. Because monodzukuri measurement is closely related to product functions and quality, research and development in this area cannot be carried out in a form which isolates measuring technologies. Rather, in R&D, monodzukuri measurement must be treated as part of a composite technology with the various other technologies that support the manufacturing process, such as design technologies and material/processing technologies. In other words, "monodzukuri measurement" is essentially different from the simple development of high-end measuring devices.[5]

Advanced measuring systems have now entered an era when anyone with sufficient funds can introduce state-of-the-art technology. Likewise, countries which were once viewed simply as a source of cheap labor are now completing plants equipped with more advanced measurement systems and production equipment than Japan's top companies. However, as a composite of design, manufacturing processes, and measuring and analysis technologies, "monodzukuri measurement" can only be materialized through the accumulation of technologies over many years, and must also be suited to the individual site and products, and therefore cannot be introduced simply by purchasing hardware. For this reason, "monodzukuri measurement" can be expected to occupy a key position supporting the international competitiveness of Japan's manufacturing industries in the future.

The aim of this article is to clarify the position of "monodzukuri measurement" and present proposals for directions in R&D on monodzukuri measurement, based on an understanding of the nature and importance of this key field.

2 What is monodzukuri measurement?

2-1 Conceptual framework of monodzukuri measurement

Monodzukuri measurement can be classified into three types, as described below. Figure 1 shows the positioning of the three types of monodzukuri measurement which will be discussed in this paper based on the stages of production in manufacturing industries. In the chart, measurement for operation and maintenance purposes is performed in the operation/use stage. However, in many cases, the measurement results are fed back to the function "monodzukuri measurement for elucidation of phenomena."

(A) Monodzukuri measurement for assurance of product performance

This type of monodzukuri measurement is performed at lines at the production site after the design and manufacturing processes have been determined in order to provide (a) assurance that products are being manufactured in accordance with specifications and (b) assurance that parts from separate production plants can be used, etc. Because a large number of measuring devices are used in lines at the production site, low cost is an

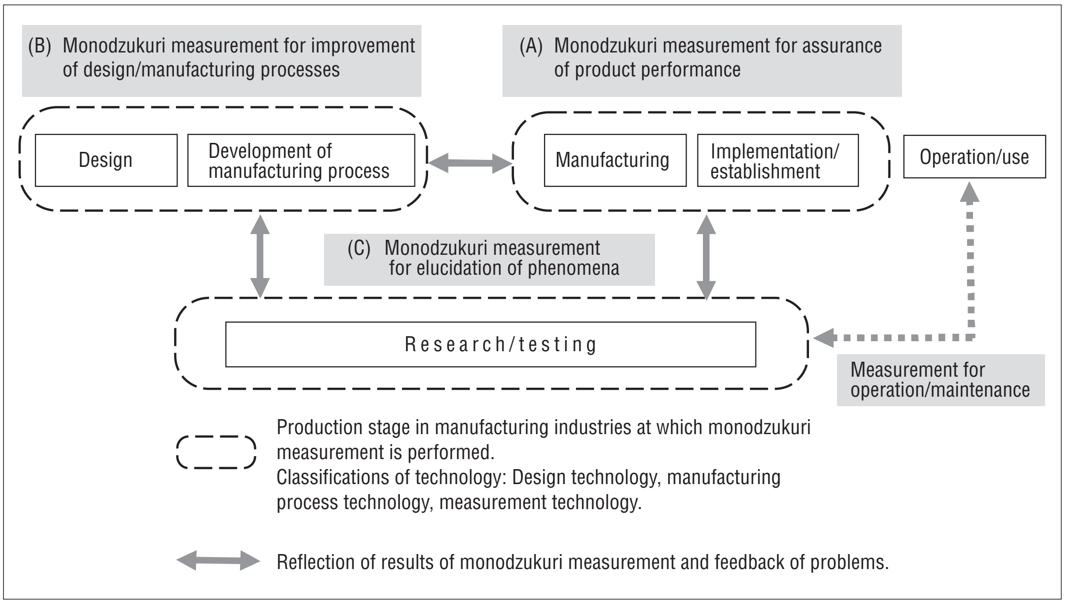

Figure 1 : Framework for monodzukuri measurement based on the stages of production in manufacturing industries

important requirement for these devices.

(B) Monodzukuri measurement for improvement of design and manufacturing processes

This monodzukuri measurement is performed to determine the design and manufacturing process in the design process and manufacturing process development stages. In particular, technologies for comparing design data and site data and in-process measurement technologies have attracted attention. Measuring devices are comparatively expensive, and multiple units are introduced.

(C) Monodzukuri measurement for elucidation of phenomena

This monodzukuri measurement function is performed in the research and testing stages in order to elucidate phenomena in the manufacturing process. For instance, in an example monodzukuri measurement of the joining mechanism in welding, accuracy in determining the joint reliability assurance period was greatly enhanced by elucidation of the phenomena in welding processes. Measuring systems of this type are generally installed in the research facilities or laboratories, and due to their extremely high cost, purchase by a single company or university may be difficult.

In this article, the above (A), (B), and (C) will be discussed in detail in Chapters 5-7, respectively.

2-2 Conditions for progress in monodzukuri measurement

(1) Digitization of physical quantities related to product performance and manufacturing processes

First, a key issue in monodzukuri measurement is identification of the physical quantities which express the fundamental performance of products. For example, in the development of a fuel cell vehicle or vehicle with improved crashworthiness, it is of first importance to determine which parameters should be measured.[5] In monodzukuri measurement, the various physical quantities related to product performance and manufacturing processes are digitized, the digitized data are supplied to those concerned, and discussions to improve the design/manufacturing process are facilitated by analysis of the data.

(2) Measurement based on a good understanding of the true nature of the technology

Because monodzukuri measurement is a composite technology involving design, the manufacturing process, and measurement, it is not appropriate to consider measurement as a technology independent from the design process and the manufacturing process. In other words, monodzukuri measurement technologies are not materialized in the measurement technology area alone. Measurement must be considered based on a good understanding of the true nature of the various technologies in the design/manufacturing processes. For example, when creating a technology map for a measuring device, the development region for the device is clarified by simply preparing a graph that shows measurement accuracy on the x-axis and the measurement range on the y-axis. However, in a technology map of monodzukuri measurement, the development region cannot be expressed adequately by these two axes. The map for monodzukuri measurement must be devised using parameters such as product performance and product cost rather than simple items of the type mentioned above.[5,6] Moreover, because monodzukuri measurement lies in this region, it is possible that there may be cases in which the development of new measuring devices is not necessary.

(3) Consideration of the uncertainty of measurement results

Internationally, measurement results always contain some uncertainty. For example, there is some uncertainty as to whether 1cm measured in another country is precisely the same as 1cm measured in Japan. Depending on the country, it is still not possible to assure the certainty of the centimeter unit as measured by local measuring equipment. However, in monodzukuri measurement, assurance that the shape and dimensions measured at plants in Japan and in other countries satisfy the same standards is necessary. This is referred to as traceability of measurement.[5,7]

(4) Building quality into the product as a corporate strategy

Manufacturing industries are strategically promoting the process of "building quality into the product" as a key corporate strategy. Total Quality Management (TQM) and quality engineering are concrete examples of this strategy. TQM is a systematic activity for the objective of managing the company's total organization effectively and efficiently, and supplying goods and services with quality that satisfies the customer in a timely fashion at an appropriate price.[8] Quality engineering is a type of engineering in which (a) the parameters that influence product quality and the manufacturing process are first identified by experimental and statistical techniques in the design stage, (b) next, deviations in the product performance are reduced by modifying the values of the parameters, and (c) finally, product performance is converged on the target performance by further adjustment of the parameter values.[9]

3 Monodzukuri measurement in Japan's Third Science & Technology Basic Plan

3-1 Monodzukuri technology field

Table 1 shows the system of Strategic prioritized S&T and Key R&D themes in the Monodzukuri Technology field.[1] Among these, the following will discuss Strategic prioritized S&T (1 technology of 2 in the field) and Key R&D themes (2 of 10 in the field) which are deeply related to monodzukuri measurement.

(1) Strategic prioritized S&T

One Strategic prioritized S&T which is taken up here is "Science-based 'visualization' technology for manufacturing that further advances Japanese-style monodzukuri technology." The objective of R&D in connection with this technology is to solve problems quickly and accelerate the creation of process innovation by the visualization of monodzukuri and by scientifically elucidating phenomena and problems which occur in the manufacturing process, enabling dissemination and accessability of the resulting information.[1] As background to the selection of

Table 1 : System of strategic prioritized S&T and key R&D themes in the monodzukuri technology field

<table>
<tr><td colspan="3">1. Situation recognition</td></tr>
<tr><td colspan="3">3. Strategic prioritized S&T (1)
Science-based visualization technology for manufacturing that further advances Japanese-style monodzukuri technology</td></tr>
<tr><td rowspan="4">2. Key R&D themes
Promotion of monodzukuri technologies (areas) serving as common infrastructure</td><td>(1)</td><td>Enhancement of fundamental monodzukuri technologies based on IT</td></tr>
<tr><td>(2)</td><td>Development of new measuring and analysis technologies/equipment and new precision processing technologies to meet the needs of monodzukuri</td></tr>
<tr><td>(3)</td><td>Advancement of monodzukuri technologies in small and medium enterprises</td></tr>
<tr><td>(4)</td><td>Monodzukuri technologies contributing to building huge mechanical systems</td></tr>
<tr><td colspan="3">3. Strategic prioritized S&T (2)
Monodzukuri process innovations to solve resource, environmental, and population problems and serve as flagship Japanese technologies</td></tr>
<tr><td rowspan="5">2. Key R&D themes
Promotion of monodzukuri technologies (areas) with the potential for innovations and breakthroughs</td><td>(5)</td><td>Monodzukuri technology to produce world-leading high value added materials</td></tr>
<tr><td>(6)</td><td>Monodzukuri innovation using robots, etc. to cope with Japan's declining-population society</td></tr>
<tr><td>(7)</td><td>Monodzukuri innovation using biotechnology</td></tr>
<tr><td>(8)</td><td>Energy saving monodzukuri processes</td></tr>
<tr><td>(9)</td><td>Resource-efficient, environment-conscious monodzukuri technology</td></tr>
<tr><td>2. Key R&D themes
Human resources development/exploitation and preservation (transmission) and refinement of skills</td><td>(10)</td><td>Promotion of the development and exploitation of human resources in monodzukuri</td></tr>
</table>

this Strategic prioritized S&T, Japan recognizes that it is necessary, at this moment in history, to take full advantage of new scientifically-based knowledge in monodzukuri technology.

(2) Important R&D themes in (1)

(a) "Development of new measuring and analysis technologies and equipment, and new precision processing technologies to meet the needs of monodzukuri"

The objective of this R&D theme is to develop more advanced/higher precision basic technologies supporting next-generation monodzukuri innovation and technologies that contribute to realizing a monodzukuri environment facilitating collaboration of workers as well as to "visualize" the technologies that ensure safety of facilities and huge mechanical systems. Concrete items include the development of measuring and analysis technologies/equipment, development of precision processing technologies, sensing, and monitoring, and technical development for realizing more advanced technologies.[1]

(b) Key R&D theme: "Monodzukuri technologies contributing to building huge mechanical systems"

The objective of this R&D theme is to develop and accumulate total technologies with international competitiveness which integrate all element technologies, including measurement, design, materials, processing, simulation, monitoring, and others, in order to manufacture and construct large mechanical systems such as aircraft, jet engines, rockets, satellites, nuclear power plants, and the like.[1]

3-2 Nanotechnology and materials field

The promotional strategy for the "Nanotechnology and Materials Field"[10] in the Third Science & Technology Basic Plan also includes one Strategic prioritized S&T (out of 10 in the field) and two Key R&D themes (out of 29) which are related to monodzukuri measurement technologies. The content of these items is outlined below.

(1) Strategic prioritized S&T

"Advanced nanocharacterization and nanofabrication technologies" is mentioned as one Strategically prioritized S&T, aiming not only at observation of shape and structure, but also the development of analysis/physical property measurement techniques with nanometer resolution, dramatic improvement in fabrication techniques, and integration with measurement.[10] As the background for selection of this item, advanced nanocharacterization and nanofabrication technologies will enable technical progress not only in the Nanotechnology and Materials field, but also in other fields of advanced science and technology such as the life sciences and IT, and in environmental measurement and clinical medicine, and is expected to play an important role in creating international competitiveness in industry, beginning with manufacturing.

(2) Key R&D themes

(a) "Cutting-edge nano-measurement and nano-processing technology"

The objectives of this theme are to enhance the level of research in the Nanotechnology and Materials field, including discovery of new phenomena and new functions by the development of new monodzukuri measurement/processing technologies, and to expand the range of industry and strengthen international competitiveness by developing new measurement, processing, and analysis systems.

(b) "Measurement, processing, and creation technologies making advanced use of electron beam technology"

The aim of this theme is to contribute to the discovery of new phenomena and elucidation of principles in materials and ecosystems by further development of electron/ion beam, X-ray, and neutron beam technologies, in which Japan has a high accumulation of technologies, and to enable advanced use of these technologies to realize a more advanced level in industrial fields and strength the competitiveness of industry.

4 Monodzukuri measurement in "Future Science & Technology in Japan toward the Year 2035"

In "Future Science & Technology in Japan toward the Year 2035," four surveys were conducted in order to provide useful information when studying priorities in the Third Science & Technology Basic Plan.[11] Among these, the "Delphi Survey" and "Survey of Development Scenarios for Key Scientific Fields" mentioned monodzukuri measurement. In the Manufacturing field[12] of the Delphi Survey, "Techniques for practical use of measurement of length, displacement, and surface roughness to the angstrom level and measurement to the femtosecond level in manufacturing processes" was mentioned as a theme in the "Nano-processing and micro-processing technology" region. In the Nanotechnology and Materials field[13] of the Delphi Survey, nano-measurement is understood as the basis of nanotechnology fields such as nano-processing and nano-creation. This study also described nano-measurement and nano-processing as essentially two sides of the same coin. The Survey of Development Scenarios for Key Scientific Fields mentioned "measurement technologies" in its development scenarios. This study described measurement technology in chemistry as a systematized technology consisting of a combination of a number of individual technologies, noting that the technologies which support it cover a wide range of fields, and went on to argue that this is not limited to chemistry, but is also true of measurement technologies in other fields of science and technology.[14]

5 Monodzukuri measurement for assurance of product performance

5-1 *Issues for assurance that products conform to specifications*

(1) Identification of measurement conditions and interpretation of measurement results

To provide assurance that products have been manufactured in accordance with specifications, it is necessary, first, to derive the measurement timing and items from the design specification, and then to interpret the measurement results. Figure 2 shows an example of the necessary objects of measurement when manufacturing

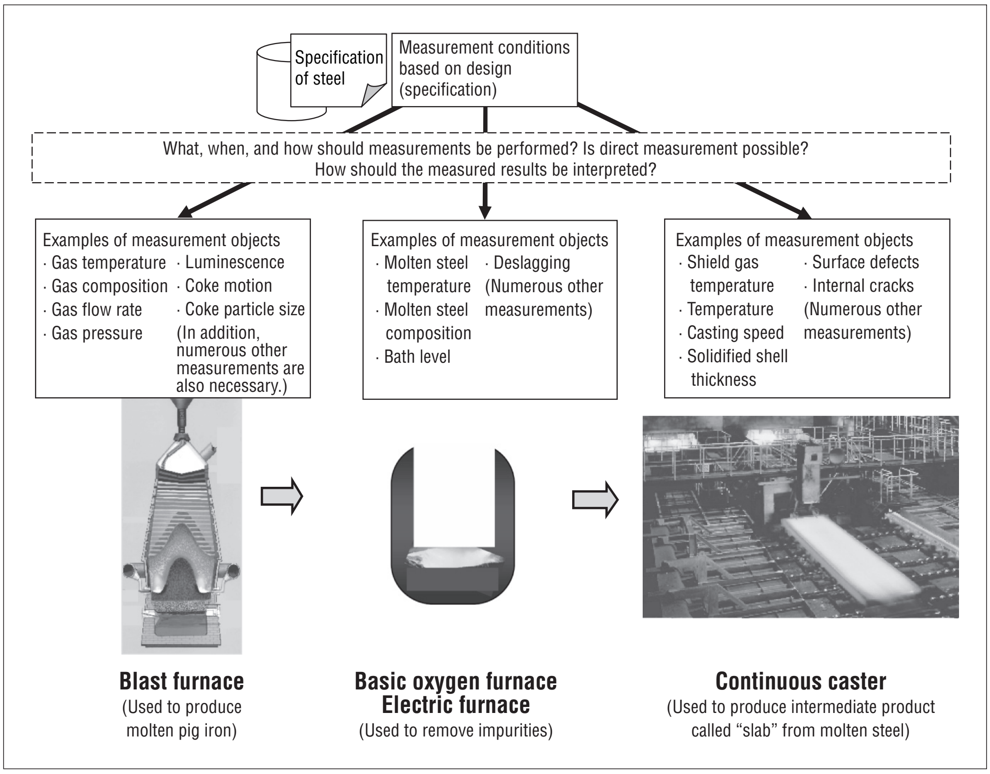

Figure 2 : Monodzukuri measurement for assurance of product performance; Example of manufacture of steel products

Prepared by the STFC based on references[15 and 16].

steel products. It is indispensable to derive the measurement conditions from the specification of the steel, which is determined in the design process. For example, in the manufacture of high quality steel, it is necessary to determine the timing of temperature measurements and the allowable limits of temperature as measurement conditions based on technical development extending over many years, and to interpret the measured results correctly.

(2) Selection of measurement method

As shown in Figure 3, even when simply measuring the diameter of a hole, measurement accuracy is higher when measurement is performed at 3 equidistant points than with 3 points in one part. Furthermore, because geometrical tolerances are applied to shape (See Figure 3.), measurement accuracy will differ depending on the positions measured. Thus, for high accuracy measurement, an appropriate measurement method must be selected, depending on the purpose. When measuring complex 3-dimensional shapes using a 3D measuring device, an angle exists between the surface being measured and the measuring pin of the device, and the position of the tip of the measuring pin in contact with surface will therefore change at the measurement location. For this reason, it is necessary to find a measurement method which is capable of measuring the surface shape with high accuracy. As mentioned previously, simply purchasing a high performance 3D measuring device does not guarantee that high accuracy measurement will be possible immediately.

(3) Separation and correction of error

- Correction of effect of temperature on measurement results

The temperature set as a standard in the specification when using machine tools and various types of manufacturing equipment is in principle 20°C. In design work, standard temperature can also be considered 20°C. However, because the temperature at production lines may reach 40°C, it is necessary to correct the measured results for temperature. Moreover, with increasing use of materials with different expansion coefficient in parts that require high, nanoscale accuracy, techniques for correcting for the effect of temperature on measurement results have become even more important than in the past.

- Calibration of measuring devices

Measuring equipment include devices that use mechanically complex mechanisms or multiple light sensors. The relative positions of the parts that comprise these devices change over time, if only slightly. To correct for these changes, it is necessary to calibrate the device before measurement. In many cases, tools called artifacts are used in calibration.[5]

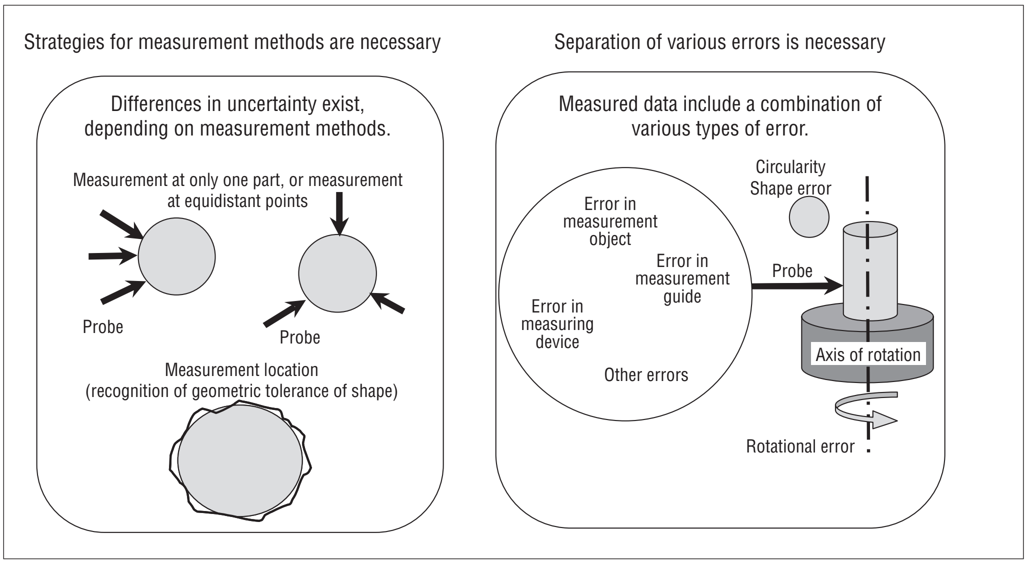

Figure 3 : Example of issues at manufacturing lines

Prepared by the STFC based on reference[17].

- Techniques for separating various kinds of error

In addition to error in the object of measurement, measured data also include error attributable to the measuring device, measurement guide, etc. It is therefore necessary to separate the error attributable to the object of measurement from the measurement results (See Figure 3.). Algorithmic methods based on numerical models of error are used in techniques for separating error.[5,17] Research and development on this subject takes advantage of applied mathematics.[17] Even in the measurement of circles, which appears simple at first glance, it is not possible to develop a measuring device without separation of error.

5-2 Issues for assurance of product quality under an international division of labor

With the progressive international division of labor and worldwide dispersion of manufacturing bases in today's global economy, it is necessary to secure international consistency in measurement standards in order to assure the quality of products which are manufactured using parts from different plants. This lends particular importance to Japan's efforts in international standardization in the area of monodzukuri measurement technologies. The Intellectual Property Strategic Program Promotion Network established in the Japanese Cabinet announced a "Comprehensive Strategy for International Standards" in December 2006, expressing the view that a strategic response to international standardization by Japan is necessary.[19] In international standardization, the viewpoint of healthy competition and cooperation with the Asian nations is important, as an increasing number of manufacturing bases under the international division of labor are expected to be located in these nations in the future. As part of this, it is desirable that Japan take the initiative in international standardization.[1,4] The following outlines issues for assurance of production quality under the international division of labor.

(1) Establishment of international traceability

To assure the absolute correctness of measurement results, it is necessary to establish traceability for physical quantities such as length.

For example, if a rotating shaft and bearing, each with a diameter and shaft hole of 20mm, are manufactured in separate countries, the methods of calibrating the measuring devices used to measure this 20mm must be consistent in the two countries. Problems will arise if the shaft or the bearing hole is larger than a true 20mm, exceeding the dimensional tolerance range, as it will be impossible to insert the shaft in the hole or the shaft will have excessive looseness, making it impossible to use these parts in products. In actuality, traceability cannot be called adequate in some countries where Japanese industries have established manufacturing operations.[5,7]

(2) Establishment of international notation system for parts

In part procurement spanning more than one country, parts which are different from the intended design may be produced if different methods of notation are used in each country. For this reason, the creation of standards for numerical notation of part dimensions, shape, and surface properties is important. It is necessary to incorporate a notation system for parts in standardization in the ISO (International Organization for Standardization). The ISO's TC213 (Geometrical Product Specifications: GPS) technical committee is creating a system of standards for accurate geometrical notation of the dimensions, shape, and surface properties of parts which is directly coupled with the functions of parts.[5]

6 Monodzukuri measurement for improvement of design and manufacturing processes

The selection of objects of measurement is determined by an analysis to identify which measurement locations will provide measurement results that are useful in improvement of the

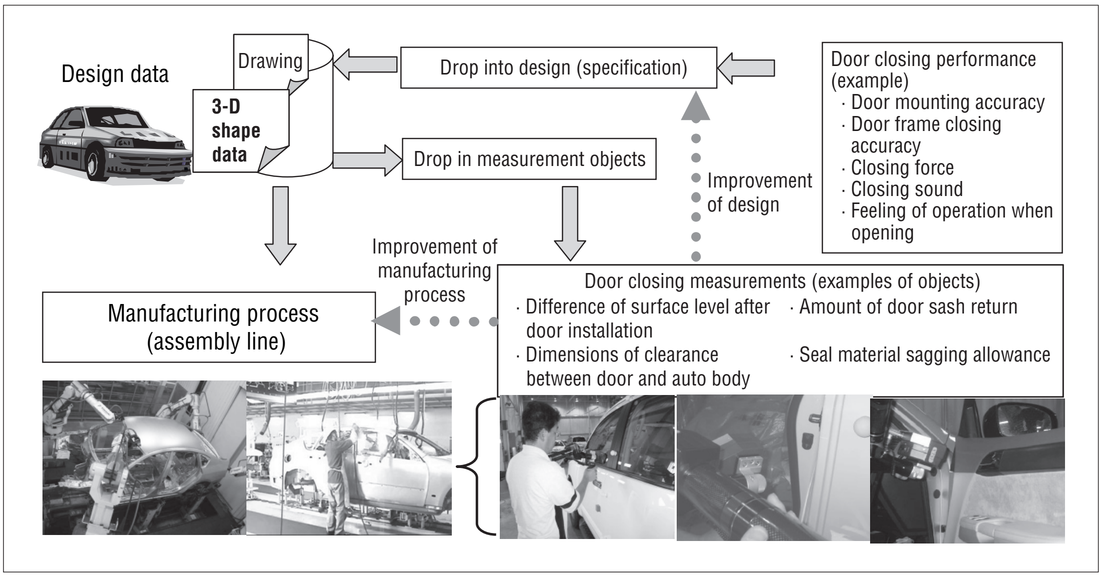

Figure 4 : Monodzukuri measurement for improvement of design and manufacturing processes: Example of measurement of automobile door closing

Prepared by the STFC based on reference [18].

design and manufacturing processes, based mainly on the design data. Without knowing the design, it is impossible to obtain useful measurement results, even if measurements are performed correctly. Thus, monodzukuri measurement for improvement of the design and manufacturing processes is performed as an integrated technology, including design, the manufacturing process, and measurement as such. Figure 4 shows an example of measurement of the closing of an automobile door.

In monodzukuri measurement for improvement of the design and manufacturing processes, technologies for comparison of design data and manufacturing site data and in-process measurement have attracted attention. The following describes these two technologies.

(1) Technology for comparison of design data and manufacturing site data

This technology compares, for example, design data and data obtained by measuring prototype products or work ("work" refers to assembled or processed products before completion) in the manufacturing process. If differences are found between the two sets of data as a result of the comparison, the cause is identified and the design and manufacturing process are improved to eliminate the cause. Because measurement of the surface and 3-dimensional shape are possible with this technology, considerable more information can be obtained than with point measurements, and various types of analyses are possible using this information. Figure 5 shows an example of a study in which 3D shape data on a prototype product measured using a laser measuring device and 3D shape data prepared in the design stage using CAD were compared, and the cause of a difference between the two data sets was identified.

(2) In-process measurement technology

In-process measurement refers, for example, to measurement of a part being machined with a machine tool as the machining process continues during processing. The incomplete part being machined is called "work." In-process measurement is necessary to avoid gage deviations which occur when the work is measured after being removed from the machine or deviations in the mounting position of the work. Because in-process measurement is performed while the machine is actually moving, the measuring device must satisfy specifications that minimize the effect of moving structural parts of the machine, such as the tool which may hinder measurement, vibration of the machine, and similar factors. Figure 5 shows an example of in-process measurement for analysis of the manufacturing process in a processing line.

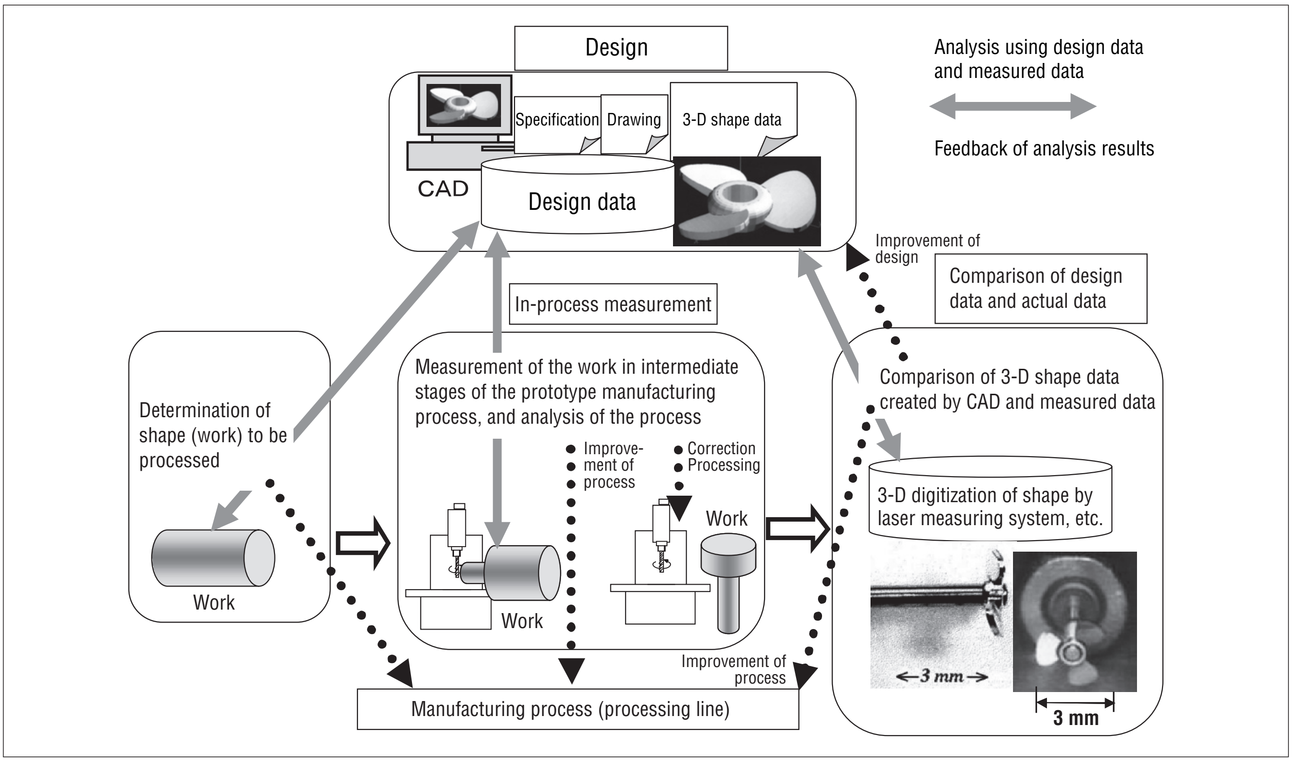

Figure 5 : Examples of comparison of design data and actual data and in-process measurement

Prepared by the STFC based on reference [5], referring to [6, 7], etc.

7 Monodzukuri measurement for elucidation of phenomena

Monodzukuri measurement for elucidation of various types of phenomena that occur in manufacturing processes from their mechanisms is also necessary. This requires a style of research and development in which measurement conditions are decided making full use of fundamental science such as solid state physics and material structural science, devices are created for these measurements, measurements are performed and a model is proposed, and finally the mechanism is elucidated. As an example of this type of research, Figure 6 shows the content of research to elucidate the joining mechanism in welding using the SPring-8, which is Japan's 3rd generation large-scale synchrotron facility.[20,21]

In order to elucidate the joining mechanism, welding researchers generally consider it necessary to measure the micro-phenomena associated with changes in the metal microstructure in the joint in time series with a temporal resolution of 0.05sec using the same moving heat source as in actual welding. This condition for resolution was derived theoretically based on metal microstructural science and joining science. To conduct experiments which satisfy this condition, R&D was carried out by creating an X-ray detector with 0.05sec temporal resolution and an experimental system for performing welding with a moving heat source inside an experimental hatch in the high-intensity beamline at SPring-8 (See Figure 6.). This research succeeded in observing the δ phase in the metallic microstructure which, among the micro-phenomena related to changes in the metal microstructure during welding, had not been well understood in the past. Measurement of the micro-phenomena associated with changes in the metal microstructure and elucidation of the joining mechanism will make it possible to establish stricter design specifications which satisfy product performance requirements. As a result, it will be possible to avoid unnecessarily high safety factors in structural design and to determine the period over which joint reliability can be guaranteed with higher accuracy.

On the other hand, similar research has also been carried out by physicists at the Lawrence Livermore National Laboratory in the United States.[22] Although that work has been praised

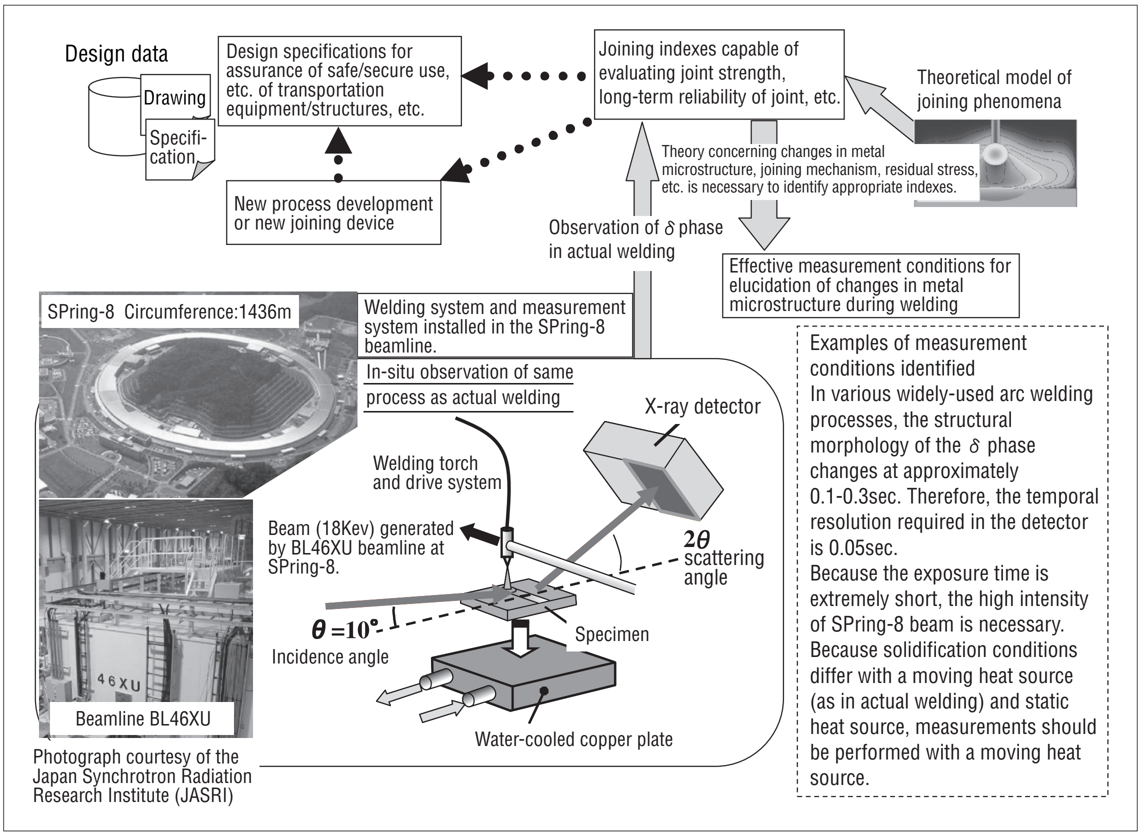

Figure 6 : Monodzukuri measurement for elucidation of phenomena: Example of elucidation of welding mechanism

Prepared by the STFC based on reference [21], referring to [20, 23], etc.

for its achievement in developing a technique for analyzing phase transformation in metals, a static heat source was used with the experimental measuring device, and not a moving heat source like that used in actual welding. Because the phenomena associated with changes in the metal microstructure are different with a static heat source, the results of this research is somewhat lacking in validity from the viewpoint of elucidation of phenomena in manufacturing involving joining by welding. It is more difficult to realize an experimental device with a moving heat source than with a stationary source. Thus, as described here, experimental research on manufacturing phenomena is the basis for R&D on monodzukuri measurement for elucidation of phenomena.

8 Important viewpoints for advancement of monodzukuri measurement

Although Japanese companies are now making daily efforts to enhance their international competitiveness in the face of fierce international competition, scientifically-grounded monodzukuri measurement will occupy an increasingly key position in maintaining the international competitiveness of Japan's manufacturing industries in the future. The following summarizes the key points when considering monodzukuri measurement.

(1) In R&D on monodzukuri measurement, treatment as a composite technology including design, the manufacturing process, and measurement is indispensable.

The above-mentioned measures for the three types of monodzukuri measurement discussed in this paper may be summarized as follows.

(A) Monodzukuri measurement for assurance of product performance

In monodzukuri measurement for assurance of product performance, it is important to determine the conditions for measurement, including measurement points, measurement methods, types of data, and the like. These are derived from the design specification. Analysis of measurement results must be based on the design/manufacturing technologies. Techniques for correcting for the effect of temperature on measurement results, calibrating measuring devices, and separating various kinds of error are also necessary.

(B) Monodzukuri measurement for improvement of design and manufacturing processes

For improvement of the design and manufacturing processes, one key point is comparison of design data and measured data and analysis of shape differences discovered thereby. In in-process measurement on processing lines, measurements are performed while machines are actually in motion; therefore, measuring devices must satisfy specifications that minimize the effects of moving structural parts of the machine, such as the tool, which may hinder measurement, machine vibration, etc. Integration of design, the manufacturing process, and measurement makes it possible to realize monodzukuri measurement for improvement of design and manufacturing processes.

(C) Monodzukuri measurement for elucidation of phenomena

Monodzukuri measurement is also necessary for elucidation of phenomena in the manufacturing process based on the mechanism of those phenomena. Here, it is necessary to determine the measurement conditions and conduct R&D to elucidate the mechanism of phenomena taking full advantage of fundamental science, such as solid state physics and material microstructural science.

(2) As a national project, monodzukuri measurement should be discussed based on an overview of the issues involved as a whole.

Large-scale competitive funding by the Japanese government for measurement is provided under MEXT's "Development of Systems and Technology for Advanced Measurement and Analysis" program (distributed mainly by the Japan Science and Technology Agency).[24] In the "8 sector budgeting method for research and development responding to policy issues" laid out in 2006 by the Bureau of the Council for Science and Technology Policy, this program is focused entirely on the monodzukuri field.

Under this system, the following two programs are being developed with the aim of promoting development of the world's first/world's highest level measurement and analysis technologies and systems supporting original research activities.

I. Development of Systems for Advanced Measurement and Analysis (System Development Program)
Development of measurement and analysis systems which can respond to Japan's advanced research needs by implementing activities from development of element technologies to application research and production of prototypes.

II. Development of Technologies and Techniques for Advanced Measurement and Analysis (Element Technology Program)
Development of original element technologies which possess novelty and can be expected to improve dramatically the performance of measuring and analysis systems.

In this program, until FY2006, proposals for development topics were accepted only for the research development area related to systems used mainly in laboratory research (general area). However, beginning in FY2007, proposals in the development area related to systems that are expected to see use in applied situations (i.e., manufacturing sites) in the future, and not only in laboratory research, were added as new development topics. Due to the strong demand for concrete benefits from measurement and analysis technologies/systems when development is completed, the objectives of this program are not limited to "fundamental research," but also include development. Assuming this program leads to the development of world's first/world's highest level measurement and analysis technologies/systems, it will support original research activities. Moreover, results which will be useful in monodzukuri can be expected from the elucidation of phenomena in science-based manufacturing processes. A framework for the above-mentioned "Development of System and Technology for Advanced Measurement and Analysis" program is considered to contribute to (C) Monodzukuri measurement for eludication of phenomena, in the above item (1) Monodzukuri measurement as a composite technology of design, the manufacturing process, and measurement.

Needless to say, these efforts alone cannot cover the entire research field of monodzukuri measurement as a composite of design, the manufacturing process, and measurement, as described above. To realize the Strategically prioritized S&T "Science-based 'visualization' technology for manufacturing that further advances Japanese-style monodzukuri technology," which was selected in the Monodzukuri Technology field, separate policies which contribute to R&D in monodzukuri measurement as a whole are necessary. Moreover, in the event that the development of new measurement devices is carried out in the future under such a program, first, it will be necessary to establish a phase which takes an overview of the issues in monodzukuri measurement as a whole and clarifies the specifications required in new measurement devices, and then to carry out R&D on devices based on the required specifications identified as a result.

(3) Industry, academia, and government must strengthen efforts in the areas of international standardization and establishment of traceability.

A necessary requirement for quality assurance in the global manufacturing economy is technology that supports international traceability by securing international consistency in measurement standards. Standardization activities are being carried out independently by various groups, including ISO standardization mainly by the academic community, creation of measurement standards by public research institutes, and creation of internal engineering standards by global corporations, among others. In the future, however, international efforts based on strengthened collaboration among industry, academia, and government will become necessary in order to strengthen Japan's international position. Likewise, from the viewpoint of healthy competition and cooperation with the Asian nations, it is desirable that Japan takes the initiative in promoting international standardization in the field of measurement to enable further progress in the international division of labor in the future.

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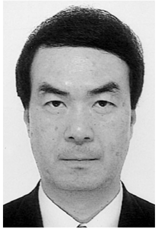

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6

Science and Technology Trends relating to Fire and Disaster Management
— Toward Innovations of Fire and Disaster Management —

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1 Introduction

Japan was formerly considered a safe country. However, deterioration of facilities due to aging etc. and unsafe conditions are progressing in many aspects of the society, as evidenced by the rapidly increasing trend in the annual death toll due to residential fires in recent years. Particularly worrisome trends include the increasing combined occurrence of 2 or more disasters such as the combined occurrence of earthquake and landslide disasters in Niigata Prefecture at the time of the Niigata Chuetsu-oki Earthquake in 2007 and increasing number of natural disasters such as typhoons and tornadoes. In addition, new factors that threaten the safety of the society and the citizens' sense of safety and security are now emerging, as seen in the new overcrowded urban spaces being created by urban development, which had languished until recently after the bursting of the Japanese economic bubble.

Against this background, the need for science and technology for achieving a safe society in which people can live with a sense of safety and security is becoming greater than ever. In the area of "Science and Technology in the Field of Fire and Disaster Management" (which contributes toward achieving such a society), too, policies and measures which make it possible to return the fruits of research to society in a more practical manner are needed now more than ever. To achieve a safe society in which people can live with a sense of safety and security, it is essential to make research outcomes available to the society both in the area of utilization of science and technology in preventing disasters, including the identification of potential hazards and establishment of safety requirements (including the incorporation of S&T outcomes in legal requirements) and in the area of utilization of science and technology in coping with disasters after they occur (including upgrading of firefighting equipment). Efforts to utilize S&T outcomes in the field of fire and disaster management in developing legal requirements have already started and have borne some fruit, but the utilization of R&D outcomes in coping with disasters after they occur, such as the utilization of R&D outcomes in science and technology in the field of fire and disaster management in improving firefighting activities, has not necessarily been pursued sufficiently.[1]

This article analyzes the current situation and issues to be addressed, particularly the issues to be addressed in order to achieve innovations in science and technology in the field of fire and disaster management, with an emphasis on the idea of utilizing science and technology in coping with disasters after they occur and minimizing damage and casualties, which has not been given sufficient consideration, and will present suggestions for innovations (Figure 1).

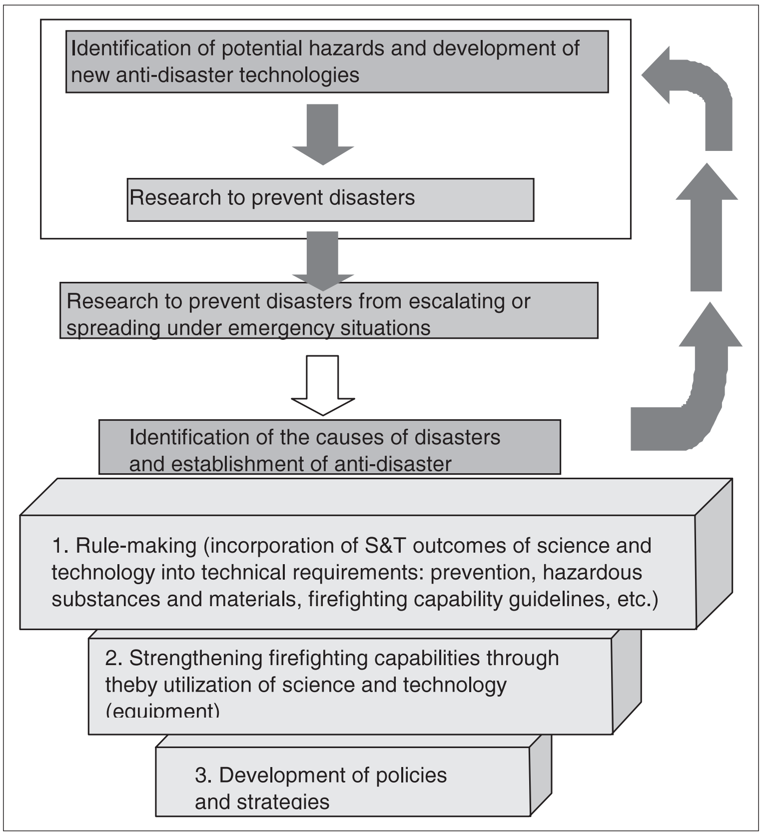

Figure 1 : Returning research outcomes in fire and disaster management to society

2 Recent trends in fire and disaster management and changes in circumstances surrounding disasters

The "Firefighting White Paper"[2] published by the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications provides a wide range of general information about accidents and disasters that have occurred in Japan, including not only fires but also disasters at facilities in which hazardous substances/materials are used or stored and petroleum complexes, natural disasters including wind and flood, volcano and earthquake disasters, and special disasters, including nuclear disasters. According to the White Paper, the annual death toll due to residential fires and the annual number of accidents at facilities in which hazardous substances/materials are used or stored have generally been on the increase in recent years. In particular, the highest number ever of leakage accidents at facilities in which hazardous substances/materials are used or stored occurred in 2006, as shown in Figure 2.

With regard to residential fires, the development and implementation of measures to protect the so-called disaster-vulnerable population (which include senior citizens, infants, and physically handicapped people) from disasters has been considered an important task. However, as a recent trend, the results of a fire statistics analysis show an increasing annual death toll of unemployed elderly people due to residential fires, as shown in Figure 3.[3]

The trend of increasing leakage accidents at facilities in which hazardous substances/materials are used or stored is considered to be attributable mainly to corrosion and general deterioration of facilities due to the aging and the recent trend to reduce maintenance expenditures. However, this assumption must be verified by detailed analyses. Although not reflected in the statistical figures, facility damage of types that were not observed in the past have occurred in recent years, including damage to the floating roofs of floating roof-type petroleum tanks due to strong winds such as those during typhoons. There is also concern that the number of traditional type accidents (such as the explosion that occurred in 2007 at a chemical factory in Joetsu City of Niigata Prefecture) may

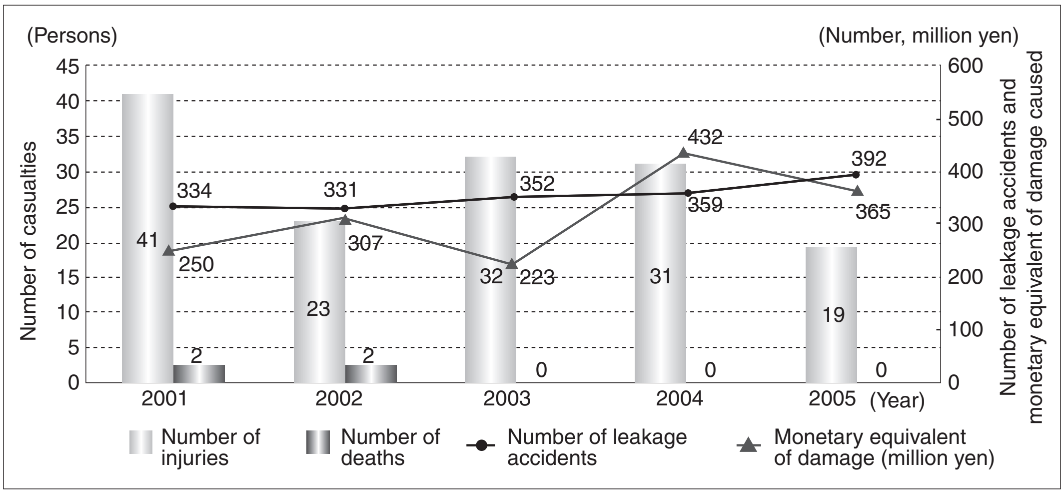

Figure 2 : Number of leakage accidents at facilities where hazardous substances/materials are used or stored and damage and casualties caused by accidents

Source: Reference [2]

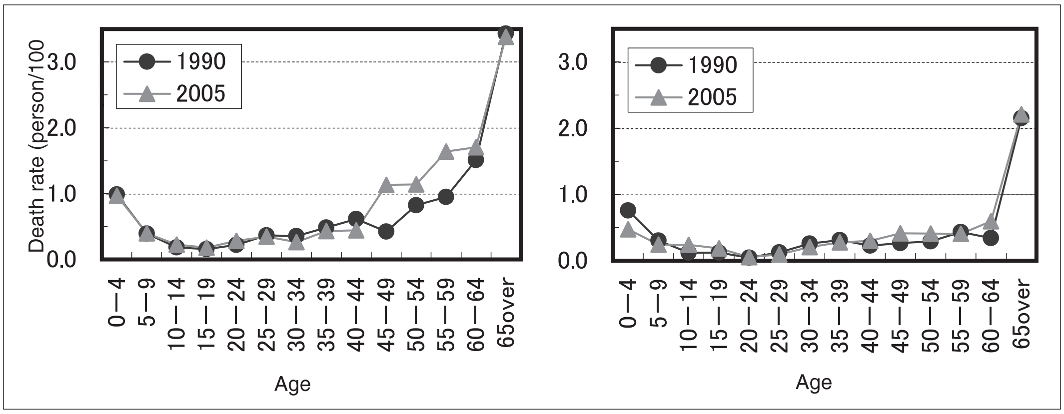

Figure 3 : Death rate due to residential fires by gender and age

Source: Reference [3]

continue to increase, as they have in recent years.

Amid the trends of increasing accidents and disaster hazards described above, the development of underground spaces in metropolitan areas, such as the construction of the Shinjuku Route of the Tokyo Metropolitan Expressway Network (Figure 4), and the construction of high-rise and large-scale buildings, which had languished until recently after the bursting of the Japanese economic bubble, are rapidly intensifying. This means that changes in conditions which increase the vulnerability of overcrowded urban spaces to disasters are progressing.[4]

With regard to natural disasters, a recent trend is that earthquake and landslide disasters occur nearly simultaneously, thereby increasing damage and casualties, as evidenced by the Niigata Chuetsu Earthquake in 2006, the Noto Hanto-oki Earthquake in 2007, and the Niigata Chuetsu-oki Earthquake in 2007.

In addition, there seems to be a recent trend in other countries toward increasing natural disasters, including giant earthquakes, Tsunamis, tornadoes, typhoons, and landslides. Examples of such disasters are the Indian Ocean Earthquake and Tsunami in 2004, Hurricane Katrina in 2005, and the South Leyte landslides in the Philippines in 2006. In recent years, large-scale flood disasters have occurred frequently around the world, including the storm surge disaster in the United States caused by Hurricane Katrina in 2005. To better prepare the country for large-scale flood disasters, the Cabinet Office has established a “Technical Investigation Committee for Countermeasures for Large-Scale Flood Disasters.” In Japan, as in many other countries, there has been a recent trend toward increasing local torrential downpours (Figure 5). The Technical Investigation Committee has stated

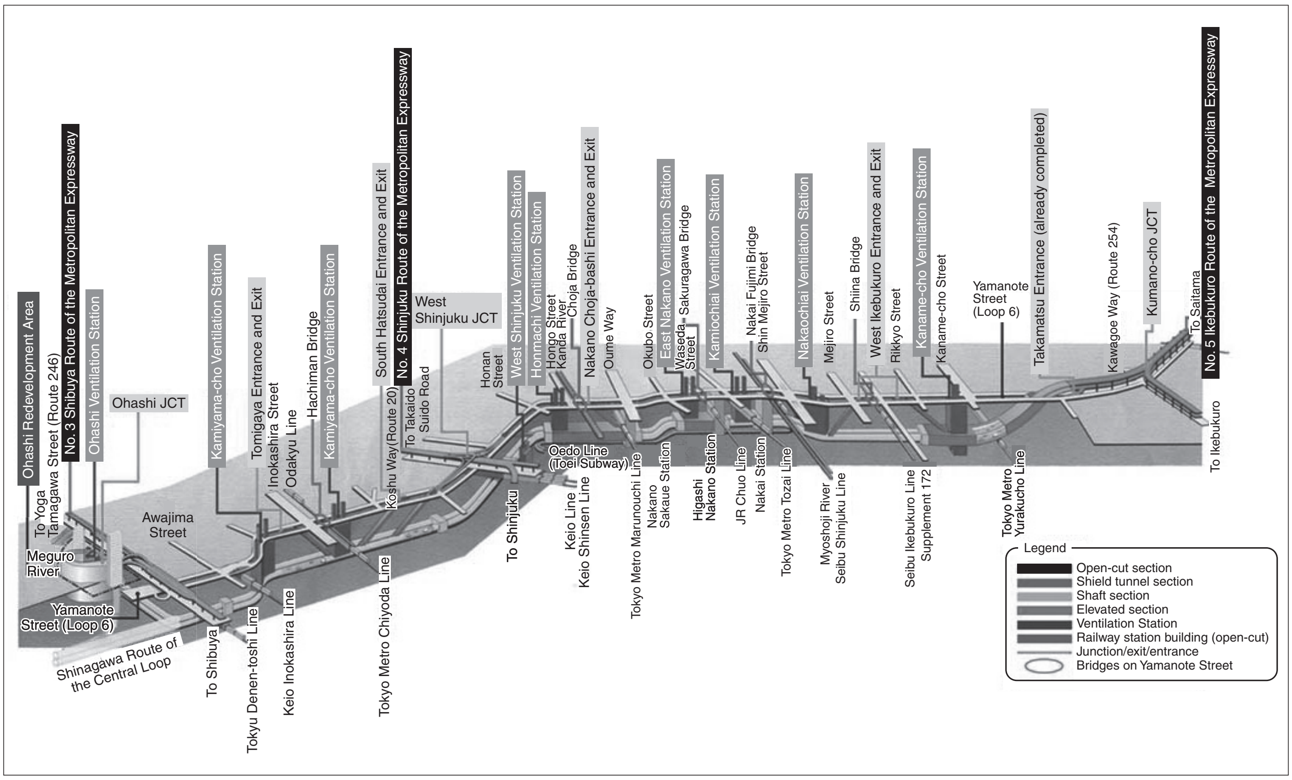

Figure 4 : Overview of project to construct the Shinjuku Route of the Central Loop of the Tokyo Metropolitan Expressway Network

Source: Reference [4]

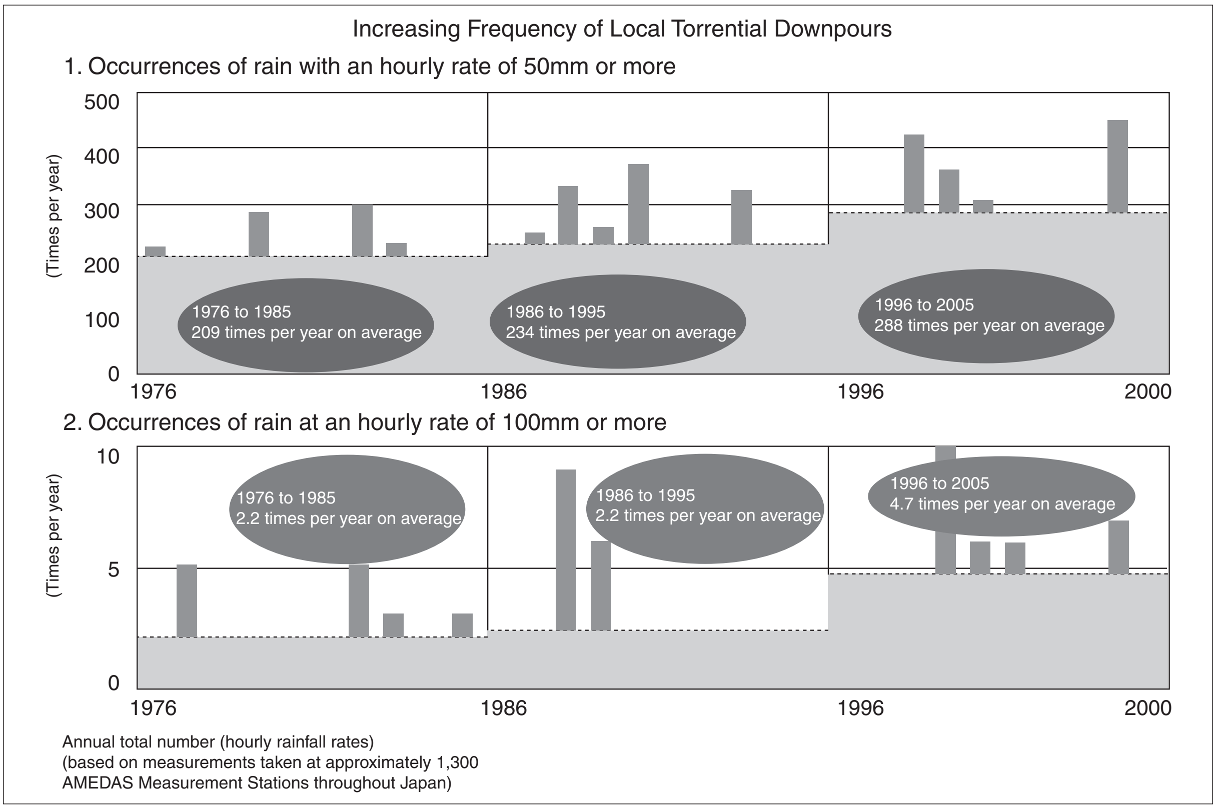

Figure 5 : Increasing frequency of local torrential downpours

Source: Document prepared by the Ministry of Land, Infrastructure and Transport that the development and implementation of countermeasures to minimize damage in the event of a large-scale flood disaster is an urgent task for the country.[5]

3 Research and development in science and technology in fire and disaster management

This chapter provides an overview of research and development in science and technology in the field of fire and disaster management being conducted in Japan by local government firefighting organizations, the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications (FDMA, MIAC), and other organizations, either individually or jointly.

3-1 Research and development by local government firefighting organizations

Currently, a total of 9 local government firefighting organizations in Japan have a dedicated department for research and development in science and technology in the field of fire and disaster management, namely, Sapporo City Fire Department, Tokyo Fire Department, Kawasaki City Fire Department, Yokohama City Safety Management Bureau, Nagoya City Fire Department, Kyoto City Fire Department, Osaka Municipal Fire Department, Kobe City Fire Bureau, and Kitakyushu City Fire Department. The fire and disaster management-related research and development departments of these 9 organizations have a total (officially prescribed) of 74 researchers and total R&D budget of approximately ¥100 million. The R&D budgets for the 9 individual fire and disaster management-related research and development departments vary widely, ranging from ¥1.8 to 50 million.

The fire and disaster management-related research and development departments of the 9 local government firefighting organizations conduct technological development and applied research to improve firefighting and other activities conducted at disaster sites, including research to improve firefighters' firefighting activities (such as research to improve/upgrade firefighting equipment and materials) and fire behavior-related research, as well as research to improve and upgrade disaster management equipment and materials and investigations, analyses and tests to identify the causes of fires.

The main recent R&D projects at the fire and disaster management-related research and development departments of the 9 local government firefighting organizations include:

- A study on the physiological load on firefighters during firefighting (Sapporo City Fire Department)
- Development of a safety management system for firefighters and a chemical analysis system for use at disaster sites (Tokyo Fire Department)
- Development of a water mist fire extinguisher nozzle (Yokohama City Safety Management Bureau)
- Development of an improved fire-retarding door (Kyoto City Fire Department)
- Development of a new fire extinguishing agent that uses a natural surface-active agent (Kitakyushu City Fire Department)

The 9 firefighting organizations jointly hold an annual "Conference of Organizations for Research for Fire and Disaster Management in Large Cities" to exchange information and opinions relating to science and technology in the field of fire and disaster management.

3-2 Research and development at the national level

A Firefighting Technology Policy Office was established in FDMA in April 2006. The FDMA and its National Research Institute of Fire and Disaster (formerly an incorporated administrative agency) conduct research to address the common challenges for all prefectures of Japan, including development of equipment for emergency firefighting assistance teams and development of an information system for coping with large-scale natural disasters including earthquakes. As of August 2007, the National Research Institute of Fire and Disaster (NRIFD) employed 26 researchers and had an annual budget of approximately ¥300 million. The main R&D projects currently being conducted are as follows.

(1) Research and development of robots

Development activities to develop practical high-performance robots that are affordable to fire headquarters have been implemented with the objective of developing robots for NBC terrorism by 2006. NBC disasters are special disasters including Nuclear disasters caused by nuclear radiation and radioactive substances, Biological disasters caused by pathogenic microorganisms such as viruses, rickettsia and microbes, and Chemical disasters caused by toxic chemicals. Building upon the robot technologies that have been developed, a new robot called "FRIGO-M",[6] which is capable of autonomously recognizing and following a firefighter wearing firefighting clothing etc., automatically recognizing and memorizing the path of movement taken, and autonomously transporting disaster victims found by the firefighter to safety by retracing the path, is currently being developed as firefighter support equipment to alleviate the physical and psychological burdens on firefighters. As shown in Figure 6, the FRIGO-M robot has a main body that is highly waterproof, dustproof, explosion-proof, and shock-resistant.

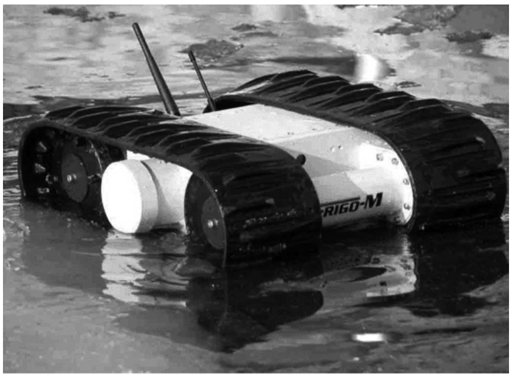

Figure 6 : FRIGO-M small crawler robot

Figure 7 shows conceptual diagrams of firefighter support equipment for special disasters such as NBC disasters.

(2) Research to develop earthquake countermeasures for petroleum tanks

During the Tokachi-oki Earthquake in 2003, 2 petroleum tanks in Tomakomai City ignited and many floating roof-type petroleum tanks were damaged. To prevent future occurrence of accidents and damage of this type, research is being conducted to develop countermeasure technologies and efforts are being made to revise the requirements of the Fire Defense Law relating to the structure of petroleum tanks. In addition, technologies to predict how floating roofs behave during earthquakes are being developed. This work includes sloshing (liquid surface movement) experiments using actual

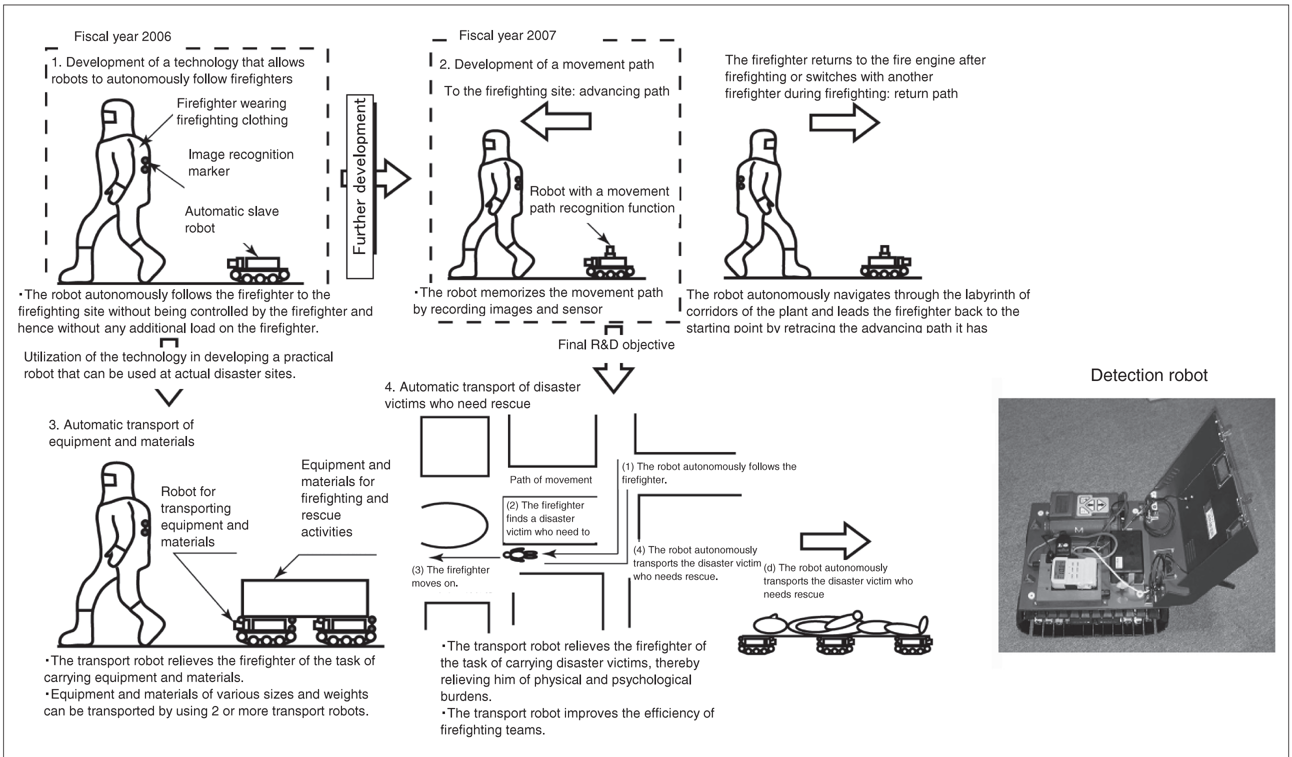

Figure 7 : Conceptual diagrams of support equipment for firefighters

petroleum tanks with diameters of up to 30m (Figure 8).

Other development which is now underway includes a method of predicting how seismic waves propagate during an earthquake and a system for predicting earthquake damage to petroleum tanks in real time immediately after the earthquake and reporting the prediction results to the organizations concerned, including the local fire headquarters. Figure 9 shows an outline of the real-time prediction system.

Figure 8 : Sloshing experiment using a model tank

Vibration generator installed in National Research Institute for Earth Science and Disaster Prevention

(3) Research relating to fire countermeasures for overcrowded urban spaces

Research relating to prediction of the spread of fires in complex, large urban spaces such as underground facilities and skyscrapers is being conducted. Specifically, R&D topics include research to establish methods of predicting the spread of fires in overcrowded urban spaces (including firestorm phenomena that occur while a fire is spreading in an urban area (Figure 10)), R&D to develop firefighting support technologies for more effective firefighting, and development of firefighting clothing for harsh firefighting environments (Figure 11).

Other R&D includes "development of information communication and decision making assistance systems to support fire and disaster management activities, including the operation

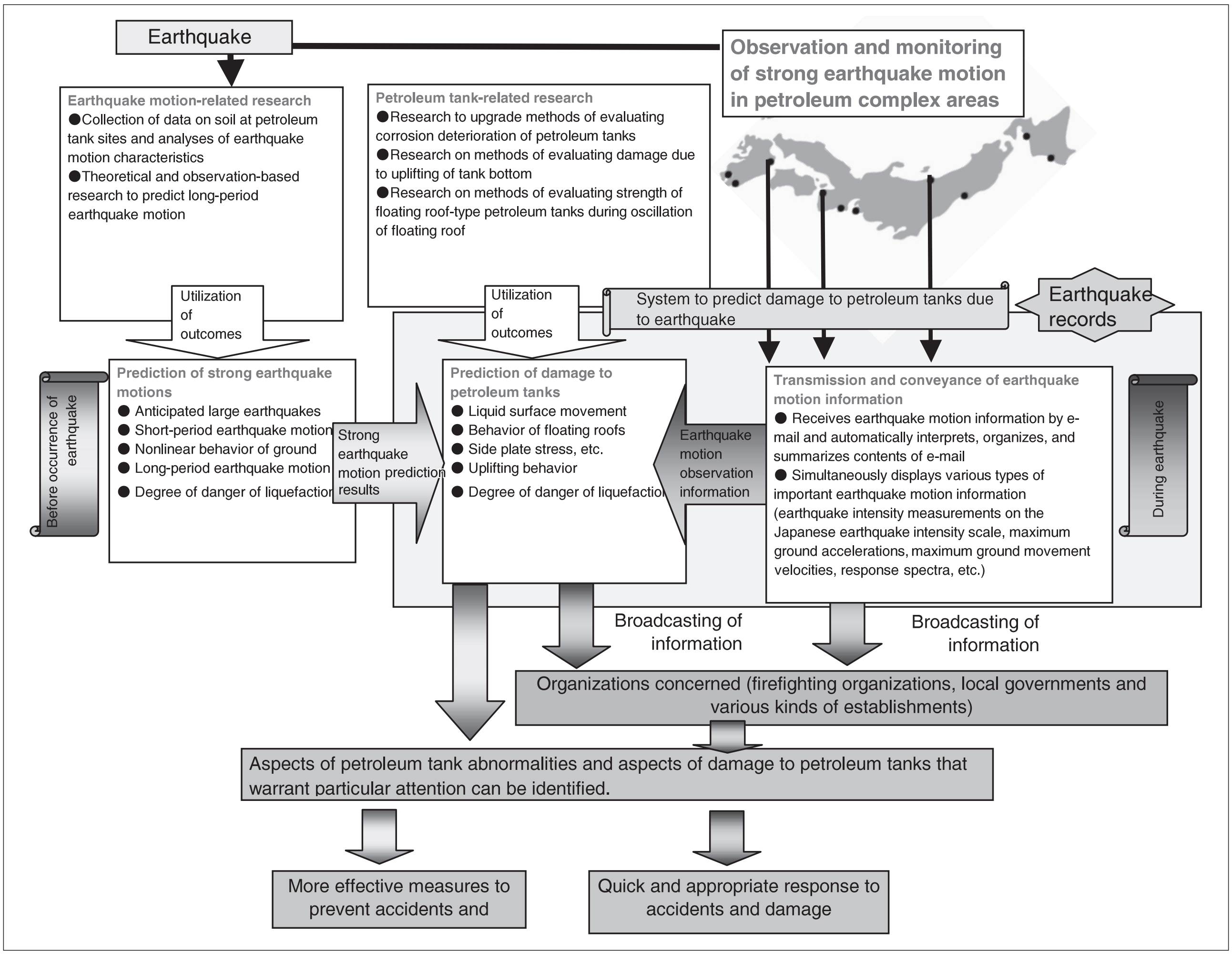

Figure 9 : Overview of real-time earthquake damage prediction system for petroleum tanks

Figure 10 : Example of firestorm phenomena downwind of fire sites

(see also the color diagram on the cover)

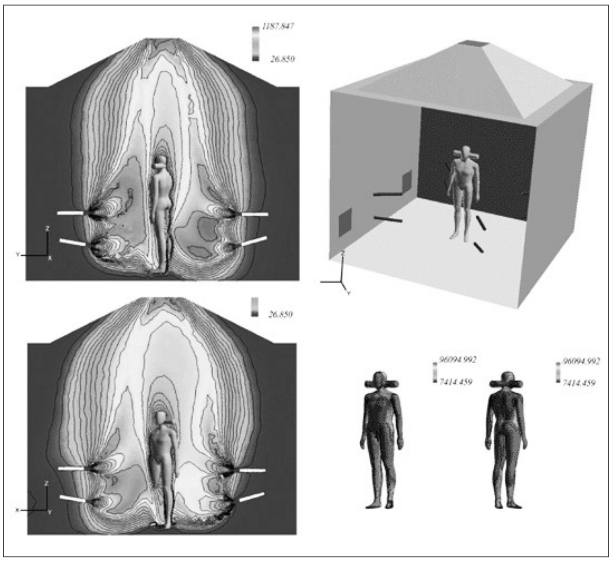

Figure 11 : Simulation of effects of heat on firefighter working in fire environment

(see also the color diagram on the cover)

of emergency firefighting assistance teams during large-scale natural disasters," "research on technologies to assess the degree of danger of explosion during fires of materials newly coming into widespread distribution/use and firefighting- and re-ignition prevention-related technologies," and "research on technologies to identify the characteristics and behavior of fires, etc. in special facilities and environments such as nuclear facilities, and technologies to ensure the safety of firefighters and reduce their physical and psychological burdens."

3-3 Research and Development under "Programs to Promote Research and Development in Science and Technology in Fire and Disaster Management"

In FY 2003, a new competitive grant program (¥350 million/year) was established to promote joint industry-government-academia research in science and technology in fire and disaster management. During the 4-year period ending at the end of FY2006, a total of 48 joint industry-government-academia research projects jointly undertaken between private sector companies, universities, local governments, etc. were selected as funded projects, including "Development of a Water Loss Reduction Type 2-Fluid Fire Extinguisher Nozzle," "Evaluation of the Effects of Tsunamis on Petroleum Tanks," and "Large-Capacity Underwater Pump with Reduced Weight and Enhanced Functionality." Two of the 48 projects, namely, "Firefighting Water Ejector Equipment Based on a Fire Extinguishing System Using a Mixed Spray of 2 Fluids (Water and Air)" and "Development of a Fire Extinguishing Agent that Uses Less Water and New Firefighting Tactics," won the Internal Affairs and Communications Minister's Award of the Joint Industry-Government-Academia Research Promotion Contributor Awards of the Council for Science and Technology Policy, Cabinet Office.

In FY2007, a "Field Needs-Oriented Research Grant Program" was established. This is a grant program for joint research projects involving firefighting organizations, and is an attempt to motivate organizations to give priority to "exit-oriented research," that is, research that places emphasis on meeting the needs of people in the field and at disaster sites. Candidate projects include "Development of Next-Generation Firefighting Clothing," "Molecule Recognition-Based Ultra-High Sensitivity Fire Detection Sensor," and "Feasibility Study for the Development of a Raft to Assist in Activities to Extinguish Full-Surface Tank Fires."

4 Priority research areas in science and technology in fire and disaster management

In order to utilize limited research resources effectively so as to obtain S&T outcomes that contribute to realizing a safe society in which people can live with a sense of safety and security, it is essential to identify the important research areas and intensively allocate research resources to them. This chapter provides an overview of the priority research areas designated by the Council for Science and Technology Policy and the FDMA of MIAC.

4-1 Priority research areas in science and technology in fire and disaster management under the Third Science and Technology Basic Plan

Under the Third Science and Technology Basic Plan established by the Council for Science and Technology Policy, "Achieving a Safe Society in which People Can Live with a Sense of Safety and Security" is designated as one main objective. Some of the research and development areas in S&T in the field of fire and disaster management have been designated as priority research areas under the research area-specific promotion strategy.[7] The designated research areas are as follows:

(1) Materials that help achieve a safe society in hich people can live with a sense of safety and security and technologies to utilize those materials

The development of materials for protective clothing and equipment that protects people from unexpected disasters and accidents, as well as the development of technologies to utilize those materials, is needed. For example, the development of materials technologies relating to materials such as highly heat resistant nano-fiber materials that can be used to produce comfortable-to-wear firefighting clothing for harsh fire environments, including fires in underground facilities and skyscrapers, and allows firefighters to work safely and effectively, and the development of technologies to evaluate such materials, have been designated as a priority research area. The required performance levels will be identified by 2008, research relating to methods to evaluate performance and functions will be conducted, including methods for evaluating the performance of nanotechnology-based firefighting clothing in terms of heat resistance, wearer's comfort, and kinematical characteristics against established requirements, and advanced firefighting clothing will be developed.

(2) Ensuring human safety during fires in various types of buildings and facilities

A database of the combustion characteristics of materials used in buildings and facilities will be constructed by FY2010 and a computer simulation-based prediction method for predicting the spread of fires in various types of spaces, including ordinary buildings, underground facilities, and skyscrapers, will be developed. In addition, the developed prediction method will be utilized to enhance evacuation and warning systems. Fire prevention measures will be strengthened and effective firefighting tactics that take into consideration the characteristics of buildings and facilities will be established.

(3) Minimizing earthquake damage to facilities where hazardous substances/materials are used or stored

In FY2006, floating roof oscillation experiments using real-scale petroleum tanks were conducted and a standard method for repairing floating roofs was developed. By FY2010, research and development will be conducted aimed at minimizing damage to facilities in which hazardous substances/materials are used or stored during large earthquakes. Research and development to develop disaster prevention measures including R&D on petroleum tanks with high resistance to long-period earthquake motion, as well as R&D to develop methods for predicting earthquake damage to petroleum tanks as a result of oscillation during an earthquake immediately after the earthquake and predicting tsunamis, will be conducted. In addition, methods for evaluating the condition of petroleum tanks that are directly relevant to their earthquake resistance characteristics will be developed, including methods of determining whether deterioration due to corrosion has occurred and the degree of deterioration without opening the tank. Figure 12 shows an overview of the development of technologies to provide accurate, real-time predictions of damages to petroleum tanks due to the oscillation of the tanks caused by earthquakes.

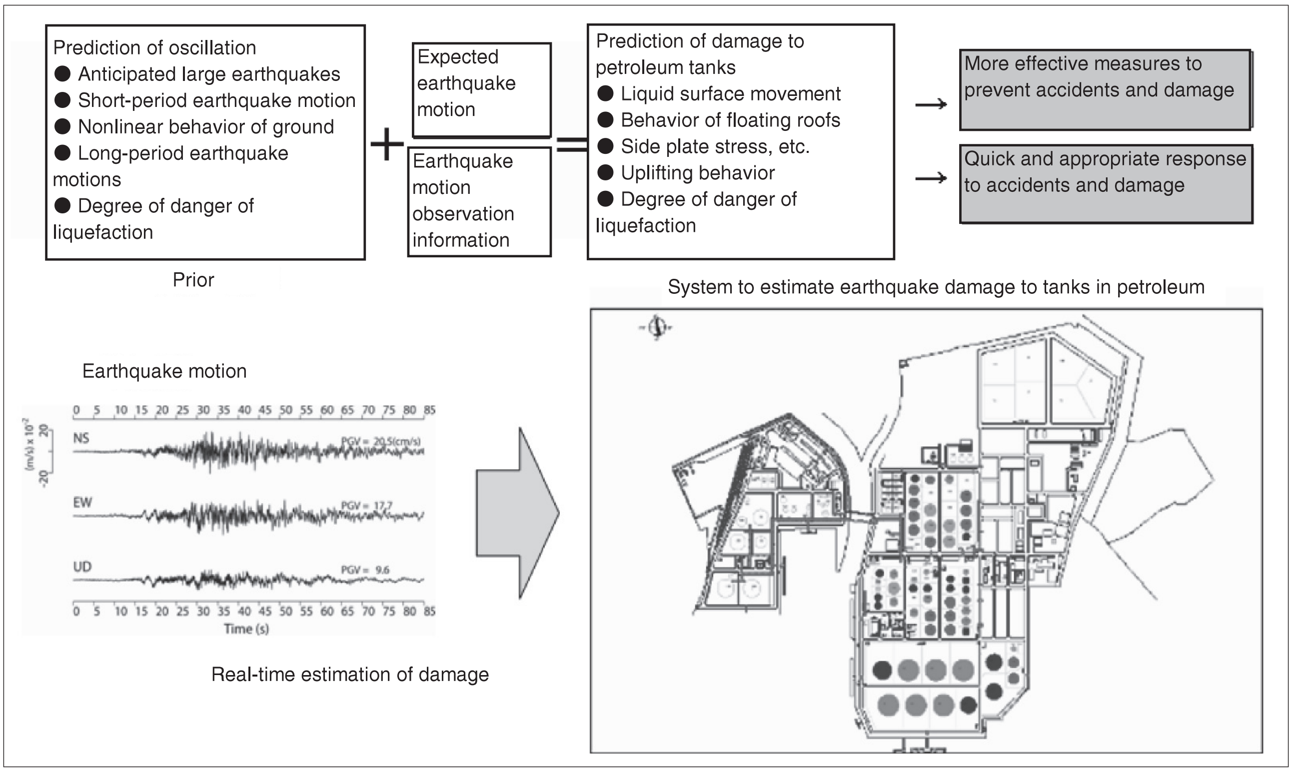

Figure 12 : Development of technologies to predict and minimize earthquake damage to facilities where hazardous substances/materials are used or stored

(4) Information systems to assist fire and disaster management activities during large-scale disasters, etc.

To minimize the damage caused by large-scale earthquakes, it is necessary to respond to disasters in a quick and appropriate manner. To appropriately respond to disasters, it is essential to collect, convey, and analyze disaster management information quickly and accurately, regardless of the type of the disaster. Systems that optimize the operation of firefighting capabilities on the assisted side (in disaster sites) will be developed by utilizing a system to simulate the spread of fires in real time, taking into account the availability of assistance teams in the prefecture and emergency assistance teams, with the objective of optimizing the operation of firefighting capabilities during simultaneous occurrence of multiple fires due to an earthquake, etc. On the assisting side, programs to assist in achieving optimal deployment of firefighting capabilities which are capable of presenting information about the appropriate assistance teams and their compositions, as well as the optimal deployment of the teams, will be developed. Specifically, assistance systems and information and communications systems that allow the national and local governments to perform effective disaster management activities will be developed by FY2010, and advanced technologies to collect, convey, and analyze information during disasters will be developed. Figure 13 provides an overview of an information system to assist in fire and disaster management activities.

(5) Ensuring human safety during special disasters and developing firefighting methods for special disasters

By FY2010, the characteristics of fires in special facilities and environments and fires due to special causes will be identified and firefighting methods for such fires will be established. Building on the results of these studies, firefighting methods for special fires will be put into actual use by FY2015. In addition, assistance equipment to ensure the safety of firefighters and reduce firefighters' physical and psychological burdens will be developed.

(6) Preventing Chemical Fires and Explosions and Fighting Chemical Fires

By FY2010, new hazardous substances (such as recycled resources) will be assessed with regard

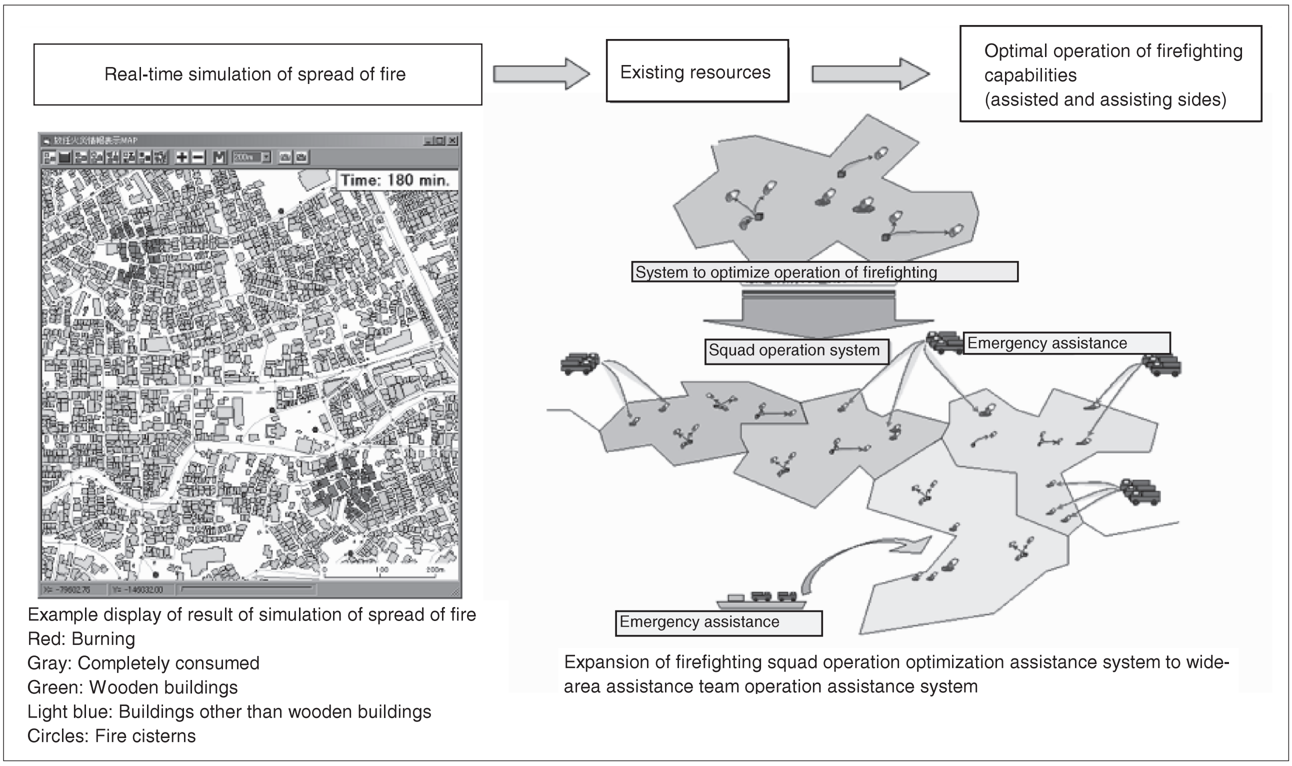

Figure 13 : Development of an information system to assist fire and disaster management activities (see also the color diagram on cover)

to their degree of danger of ignition/explosion. Methods for assessing the degree of danger of heat accumulation, danger of spontaneous ignition, danger of explosion, etc. will be developed, and relevant data will be accumulated. In addition, to better prepare for chemical leakage accidents and accidents that result in fires, technologies to fight tank fires and fires involving oil leaks will be developed, including technologies to prevent re-ignition.

4-2 Second Strategic Plan for Advancing Science and Technology in the Field of Fire and Disaster Management[8]

The Forum for Discussion on Science and Technology in the Field of Fire and Disaster Management (comprising external knowledgeable persons and chaired by Professor Emeritus Yoichi Uehara of Yokohama National University) was charged with the task of establishing, by FY2005, a plan for the future of science and technology in the field of fire and disaster management. Based on discussions of the subject, the body established the First Strategic Plan for Advancing Science and Technology in the Field of Fire and Disaster Management.[9] The First Strategic Plan was subsequently revised, taking into consideration the necessity of achieving compatibility with the Third Science and Technology Basic Plan as well as recent changes in the circumstances surrounding disasters, including fires, and general trends in science and technology. The revised plan was announced by the FDMA in February 2007 as the 2nd Strategic Plan for Advancing Science and Technology in the Field of Fire and Disaster Management.[10]

A questionnaire survey comprising 10 items and 76 sub-items concerning the urgency of introduction and practical application of technologies was conducted among fire headquarters in 100 Japanese cities (Major Cities designated under a Government Ordinance, consisting of prefectural capital cities and other cities that are considered to be equivalent thereto) prior to the establishment of the Second Strategic Plan, and the results of the survey were reflected in the Plan. The 10 items are as follows:

(1) Development of more advanced disaster management systems through utilization of information and communications technologies
(2) Development and implementation of measures to prevent and fight residential fires

(3) Qualitative improvement of disaster management capabilities
(4) Development of more advanced facilities to assist in firefighting activities and more advanced equipment and materials for firefighting activities
(5) Strengthening of measures to prevent and respond to special disasters
(6) Enhancement of measures to prevent and respond to disasters at facilities where hazardous substances/materials are being used or stored
(7) Development and implementation of more advanced rescue and lifesaving services
(8) Environmental protection considerations
(9) Internationalization-related needs
(10) Development and improvement of mechanisms for protecting the citizens of Japan

The priority R&D areas designated under the Plan are as follows:

- Research and development toward ensuring the safety of the citizens of Japan, particularly people who are likely to need rescue in the event of a disaster, such as senior citizens, and providing them with a sense of safety and security
- Research and development toward enhancing preparedness for large-scale disasters
- Research and development toward developing and implementing advanced fire and disaster management activities that utilize advanced technologies
- Research and development toward meeting the increasing lifesaving needs and developing and implementing more advanced lifesaving services

The Plan states that policies and measures must be developed and implemented to (1) enhance education and training systems so as to nurture future researchers in science and technology in the field of fire and disaster management, (2) promote the sharing of scientific and technological information in the field of fire and disaster management and (3) enhance and strengthen promotion systems based on cooperation and coordination between the national and local governments and interested organizations and industries.

5 Achieving innovation based on science and technology in fire and disaster management

5-1 Cooperation in exit-oriented research and development

This chapter outlines examples of research and development being conducted in S&T in the priority research areas described in Chapter 4 in the field of fire and disaster management with the objective of achieving innovation. All of the R&D activities described below are activities in research areas that were selected by the national government from the standpoint of the needs of the people engaged in fire and disaster management activities at the field level, from items for which certain outcomes have been obtained but no exit to practical application is envisioned. The national government has been attempting to assist R&D organizations develop R&D outcomes into scientific and technological innovations for people working at the field level by developing frameworks for cooperation and coordination between industry, government, and academia, between government organizations, and between the national and local governments.[11]

(1) R&D on nanotechnology-based firefighting clothing

Figure 14 shows the research and development being conducted to develop nanotechnology-based firefighting clothing and next-generation firefighting clothing. Under a competitive grant program sponsored by the Ministry of Economy, Trade and Industry, laboratories and research institutes of private sector companies and Independent Administrative Institutions (IAI) are developing materials, and the FDMA is analyzing data on the needs of people engaged in firefighting at the field level and developing evaluation technologies. Figure 15 shows the framework for promoting cooperation and coordination between industry, government and academia and between government organizations.

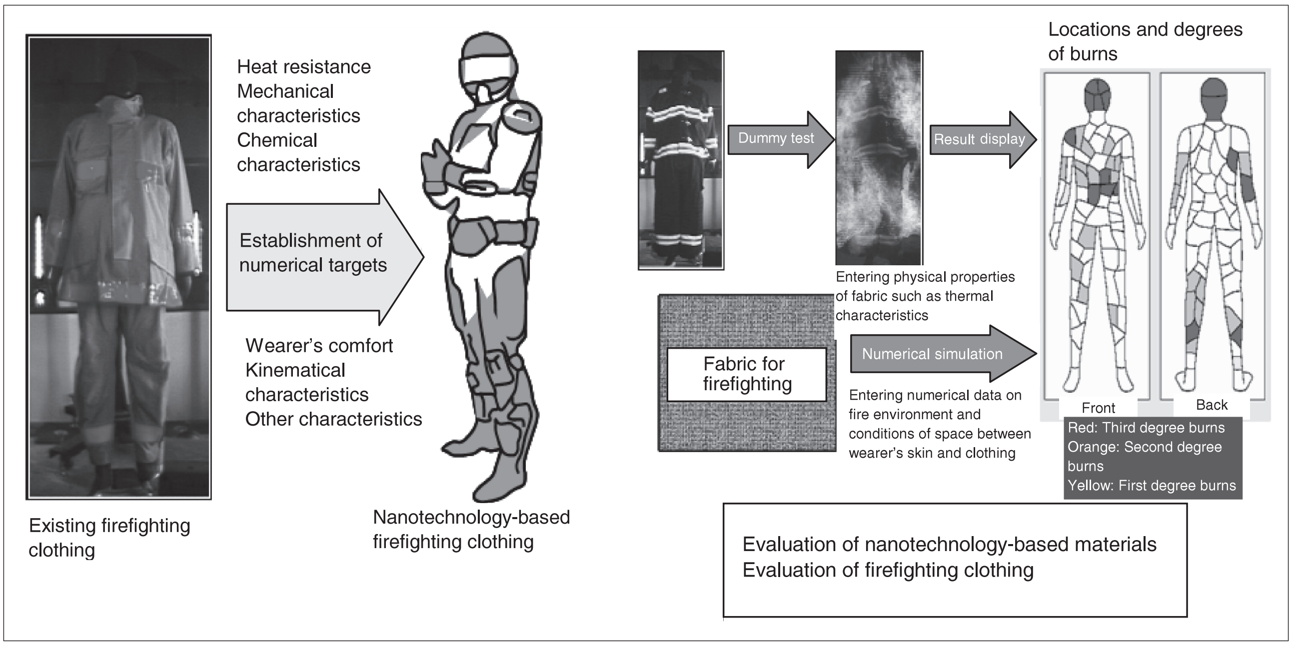

Figure 14 : Development of nanotechnology-based firefighting clothing and next-generation firefighting clothing

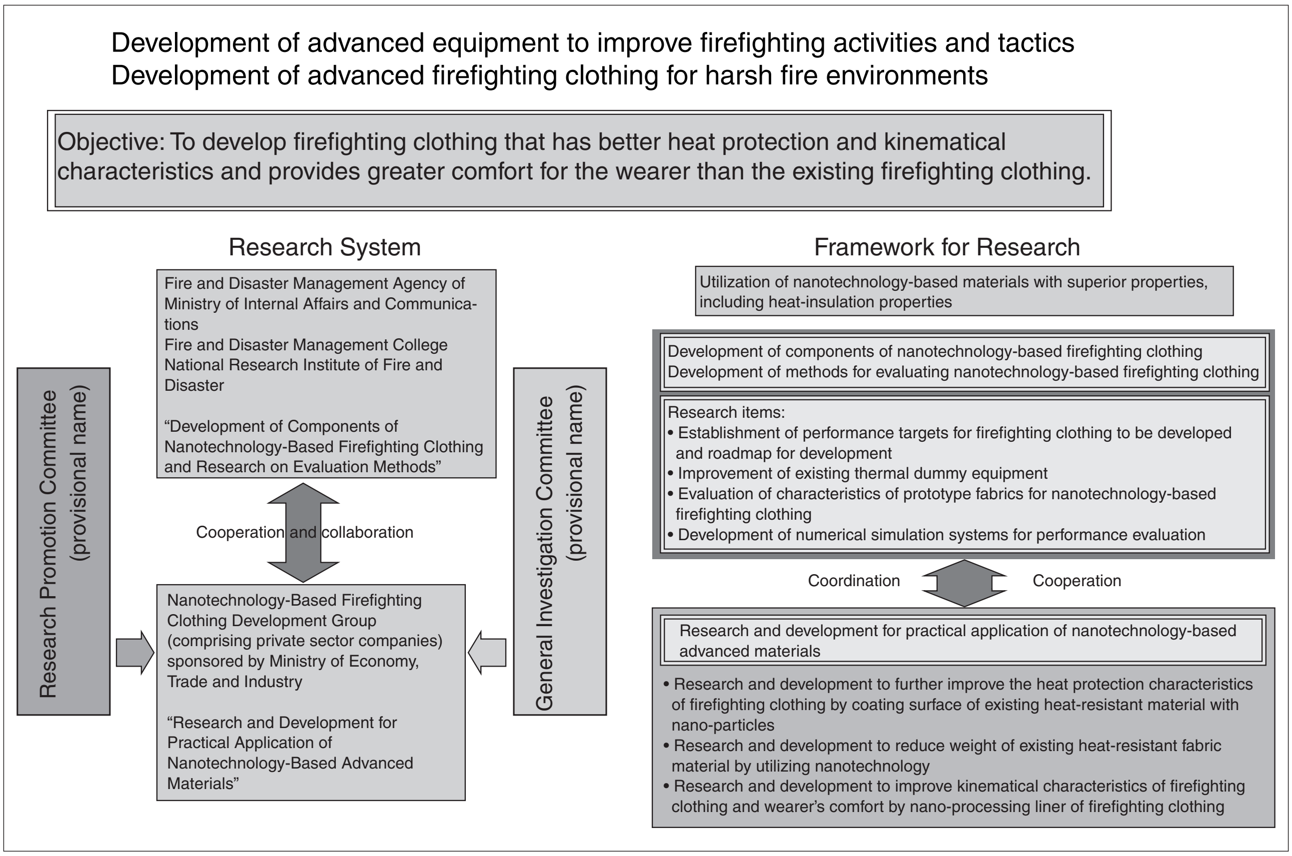

Figure 15 : Overview of system for research and development of nanotechnology-based firefighting clothing

(2) Introduction and deployment of Helisat technology

"Helisat" technology was developed by the National Institute of Information and Communications Technology (IAI) and allows helicopters and communications satellites to communicate directly with each other (Figure 16). Currently, R&D is being conducted to implement this technology in fire and disaster management helicopters operated by the national government. At the time of the Niigata Chuetsu Earthquake in 2004, earthquake damage on the ground made it difficult to relay video data from helicopters in the earthquake-stricken area, revealing the vulnerability of the existing information communication system. This R&D is

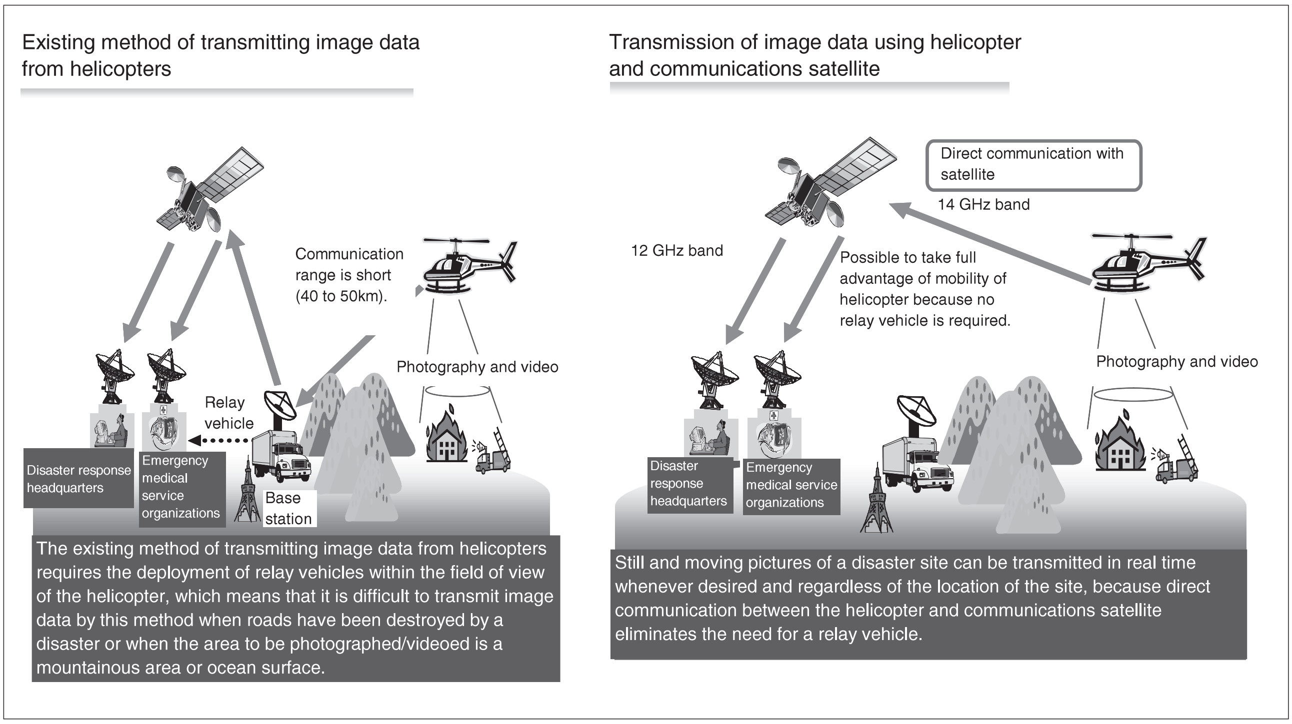

Figure 16 : Introduction of technology for direct communication between helicopters and communications satellites

being conducted with the objective of providing a technological solution to the challenge of developing means of emergency communications that do not fail during large-scale disasters. Expectations that this research and development will attain its objective are high.

(3) R&D to provide emergency assistance teams with reconnaissance and assistance robots

R&D is being conducted to deploy equipment developed with national funding (as equipment for firefighting and emergency assistance teams) at fire headquarters of local governments for practical use on a trial basis. The equipment shown in Figure 17 is being developed based on the lessons learned from exposure to sarin nerve gas of firefighters engaged in rescue work after the sarin attack on the Tokyo subway system in 1995. The target is to make this equipment capable of “moving from above the ground to subway platforms in the Kasumigaseki area and detecting and analyzing toxic substances” (The current specifications do not require that the equipment to be capable of return to the ground. The toxic substances detected are recovered after the incident is resolved). In addition, continuing R&D with national funding is being conducted with the aim of developing a low-cost version of the equipment which would only provide a subset of the functions of the full version but would be affordable to fire headquarters. The companies that have participated in research and development have commercialized the technology and started marketing products of their commercialization efforts.

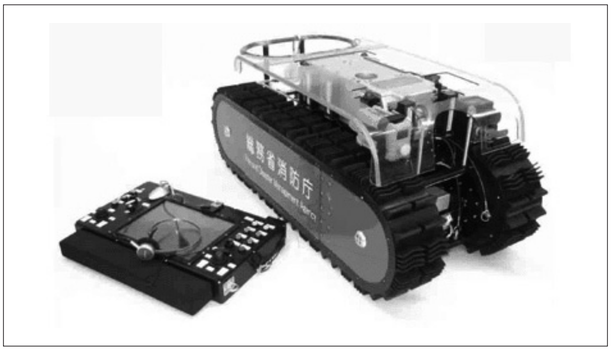

Figure 17 : Detection and exploration robot to assist in disaster response activities deployed at the Tokyo Fire Department

5-2 Efforts to develop R&D outcomes into innovations for society

This section proposes a somewhat general theory of innovation and examines the problem of why R&D outcomes fail to become useful innovations for society.

In “The Prince,” Machiavelli points out the following as reasons why it is difficult to achieve social reform: “The introduction of a new order will antagonize all people who have fared well under the old system. In addition, even those people who accept the new order only do so without eagerness. There are two reasons for the reluctance of people to accept a new order. First is the fear among people who have enjoyed advantages or comfortable lives under the old system that they might lose them, and second is the skepticism among people about the new system."[12] This observation also applies to attempts to achieve innovation for society through utilization of science and technology. That is, attempts to introduce a new technology often encounter two types of objections:

- People who have fared well without innovations tend to say, "What is wrong with being content with the existing system?"
- Because the benefits that will be brought about by an innovation (e.g. cost-benefit ratio) are usually uncertain, people tend to say, "What good will it do?"

The obstacles to the development, commercialization, and industrialization phases to achieving innovations for society through utilization of R&D outcomes are sometimes called the Devil's River, Death Valley, and Darwin's Sea, respectively. Some people argue that the development of technologies for achieving a safe society in which people can live with a sense of safety and security requires a holistic approach, that is, an approach that "grasps the overall picture of the problem," "allows the utilization of knowledge that transcends the boundaries of disciplines," and "allows problem-solving-oriented sharing of knowledge."

How, then, can we overcome these obstacles and develop R&D outcomes into innovations for society? The Apollo Program in the United States, which was carried out to send men to the moon, is considered to be an example of success, because it led to the development of the Global Positioning System, Internet, and Kevlar fiber. An analysis of examples of success, including the Apollo Program, leads to the conclusion that the key to developing R&D outcomes into innovations is to break the vicious cycle in which "the tendency that outcomes of advanced technologies and products developed from them are not initially accepted by people on the needs side who have been accustomed to traditional technologies because of a lack of track record" results in "a lack of motivation on the seeds side to invest in the advanced technologies," which in turn "dampens efforts to achieve innovations."

To overcome Devil's River, Death Valley, and Darwin's Sea obstacles, it is considered important to ensure that there will be "sophisticated specification-oriented" users in the initial phases who purchase advanced technologies and products developed from them as "first customers," enabling a virtuous cycle of innovation to begin. For example, the Global Positioning System, Internet, and Kevlar fiber would not have established their footholds if they had not been supported by national defense-related procurement in the United States. These examples suggest the conclusion that it would be easier for R&D outcomes to make their way into private-sector industries and consumer markets if there were "sophisticated specification-oriented" customers in the public sector who take development-related risks in the initial phases and create initial demand. Figure 18 presents a diagram (reproduced from a report of the Ministry of Economy, Trade and Industry) showing an overview of the government's scenario for creating initial demand for nanotechnology-based protective clothing through development and implementation of policies.

Researchers who are engaged in research and development often make the mistake of trying to define the research topic and the direction of research "on the basis of what problems they think they can solve" rather than "on the basis of what problems should be solved to attain the objective." In general, evaluations of the outcomes of a development project differ considerably between "the case where the researchers themselves are users" and "the case where the researchers are not users." The tendency that researchers "highly value technologies which they have developed" and "are critical of technologies developed by others" has also been a barrier to achieving innovations. It can be thought that a combination of these two problems has caused a situation where researchers engaged in research and development say, "We have produced research results, but

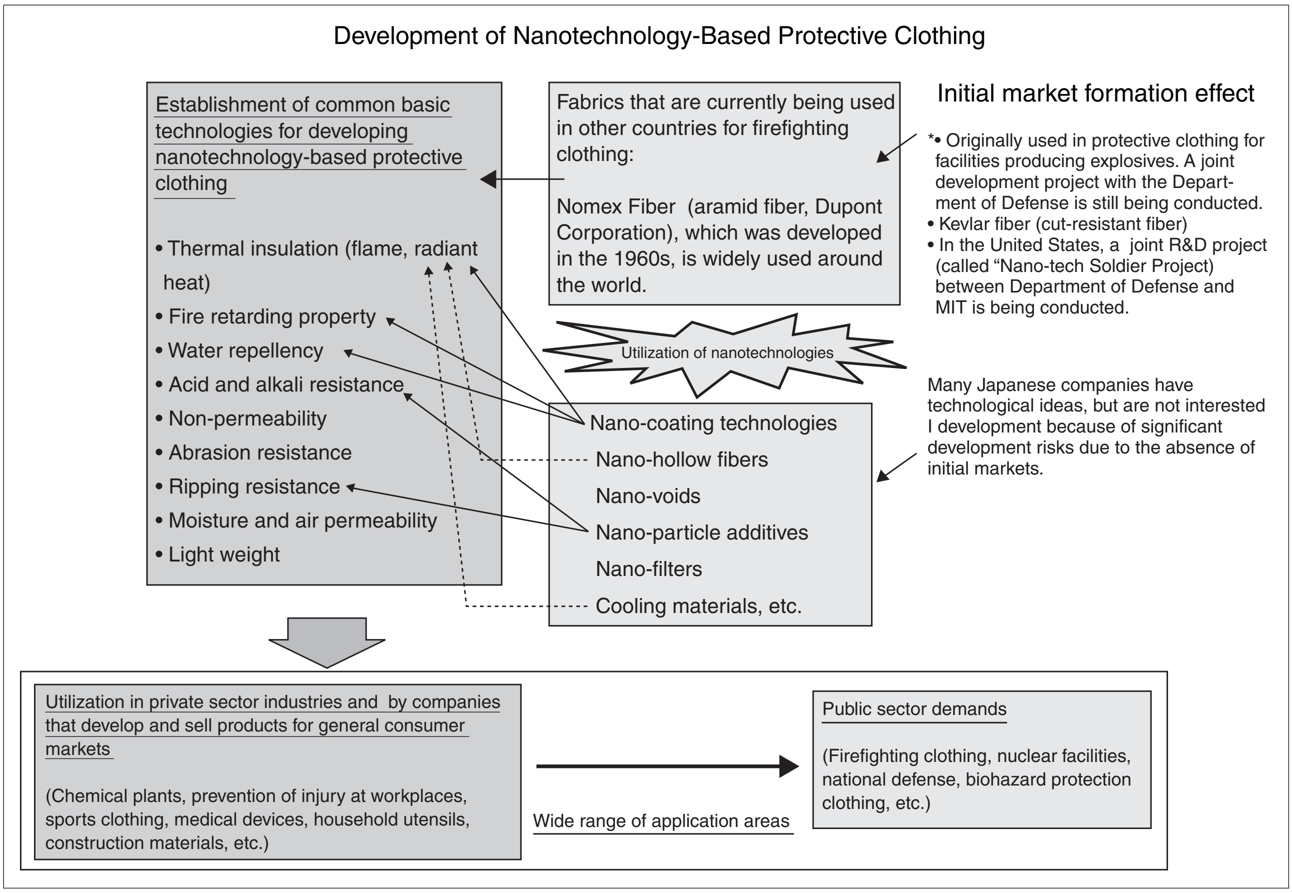

Figure 18 : Scenario for creating initial demands for nanotechnology-based protective clothing through development and implementation of policies

companies and organizations on the user side are not interested in using them for practical purposes," while companies and organizations on the user side say, "There are no research results that can be used for practical purposes." In other words, there is a significant difference between "the perspective of people on the development side" and "the perspective of people on the user side."

In science and technology in the field of fire and disaster management as well, it is reasonable to think that user involvement from the development phase will help in efforts to create initial demand through development and implementation of policies and in solving the problem of differences in perspective. In short, we believe that, in order to create an environment in which R&D outcomes are actively utilized for field level fire and disaster management activities, simply improving R&D systems is not sufficient, and it is important to consider a "mechanism that works, taking into consideration how the R&D outcomes will be valued by the procurement departments of users.[14] Such a mechanism must:

- Be capable of involving firefighting organizations from the development phase;
- Include a method to objectively evaluate the costs and benefits of the introduction of R&D outcomes; and
- Allow development to be conducted in a procurement-conscious manner.

In particular, in the case of creation of initial demand through development and implementation of policies to create demand in the public sector, in order to ensure that this is done in an objective and rational manner, it is necessary that there be sufficient accountability to the taxpayers and financial managers with regard to the new technology being considered for introduction. To that end, it is considered necessary to develop an appropriate evaluation method such as one based on a set of appropriate criteria, like those shown in Table 1.

Table 1 : Evaluation criteria for introduction of new technologies

- Evaluation of the need to introduce the technology
  Isn't it possible to solve the problem without introducing the technology? Is the technology essential to solving the problem?
- Prediction of the results of introduction of the technology and analysis of the advantages of introduction
  What is the problem that can only be solved by using the technology?
  Does it occur frequently or infrequently?
- Losses being incurred as a result of the unsolved problem
  (= How much money is available to solve the problem?)
- How much money is required to solve the problem?
- Comparison with alternative means (for example, cost, expected effects, and ease for users becoming accustomed to the technology)
- Evaluation of the credibility of the R&D researchers' assertion that the technology is "useful"

[Note] The evaluation of a technology in terms of cost requires a decision as to whether to estimate the cost required to purchase the technology in the initial introduction phase or the cost required to purchase the technology after popularization of the technology. (For example, in addition to the direct effects of introduction, the second and subsequent units tend to become less expensive than the first, which may be rather expensive.)

5-3 Major innovation-inhibiting factors unique to S&T in fire and disaster management and the need for S&T coordinators

The major innovation-inhibiting factors unique to science and technology in the fire and disaster management include:

(1) Small overall scale of the market

The total number of firefighters working at firefighting organizations in Japan (i.e., the total number of "users" for the purposes of this report) is approximately one million. Equipment-related expenditures represent no more than 10% of the total national firefighting budget of approximately ¥2,000 billion.

(2) Individual procurement of equipment and materials by more than 800 fire headquarters throughout Japan

Because the current equipment and material procurement system does not have a central command station for introduction of new technologies, researchers tend not to be strongly motivated to develop new technologies.

To solve these problems unique to S&T in fire and disaster management, it is important that the national and local governments work in close cooperation and coordination. For example, the development of standard specifications, identification of important user requirements, and introduction of joint procurement systems under the leadership of the national government can be effective in solving these problems.

For effective functioning of the above-mentioned mechanism for developing R&D outcomes into innovations for society, science and technology coordinators who can objectively understand, evaluate, and explain R&D outcomes are essential. Currently, there is a serious lack of such coordinators in Japan. Nurturing and deploying such coordinators is an important task for the future.

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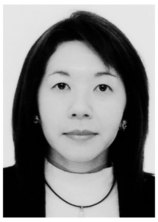

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7

Overseas Trends in the Development of Human Occupied Deep Submersibles and a Proposal for Japan's Way to Take

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1 Introduction

Japan's human occupied deep submergence vehicle, the Shinkai 6500, is the only submersible in the world capable of diving to the maximum depth of 6500m. The Shinkai 6500 was launched in 1990, began research dives in 1991, and recorded her one-thousandth dive in March 2007. This submersible has produced a number of impressive achievements in research on the topography and geology of the ocean floor, life inhabiting the deep seas, among others, not only in the seas neighboring Japan, but in oceans around the world.[1] Moreover, use of this vehicle is not limited to specialized researchers; the Shinkai 6500 has also been made available to budding researchers aiming at future science and technology, and has won an outstanding reputation in this connection as well.[2]

Since the Shinkai 6500 was launched, a variety of improvements have been made in the vehicle, and various individual parts have been replaced with high performance components. As a result, it has continued to operate safely without serious problems, thereby contributing to the establishment of technologies for safety and reliability. Nevertheless, 20 years have already passed since the Shinkai 6500 was built. Aging and obsolescence of the system as a whole are progressing, and other countries are developing and building new human occupied vehicles (HOV) which can equal or exceed the maximum depth of the Shinkai 6500. At the same time, unoccupied submersible research vehicles are also under development or in operation. Thus, the time is fast approaching when Japan must examine the significance and proper form of HOV, including what type of vehicle should be built as a successor to the Shinkai 6500.

In addition to the Shinkai 6500, Japan formerly operated a 2000m class HOV called the Shinkai 2000. When the Shinkai 2000 was taken out of service in 2004, a discussion was held on the question of whether to continue to use HOV in deep-sea research in the future, or to use remote-controlled or autonomous unoccupied vehicles.[3,4] One side in this debate consisted of people who held that HOV are necessary and indispensable because researchers investigating deep-sea life rely on direct observation by the naked eye. The other side advocated using unoccupied vehicles with high performance cameras as a tool for wide-ranging observation. This group argued that, if the region that can be observed clearly is narrow and satisfactory observation is impossible, it would be possible to develop camera technologies that enable 3-dimensional observation and expanded observation in the depth direction. In this discussion, some also expressed the opinion that a true unoccupied vehicle would be a completely autonomous underwater vehicle with artificial intelligence. Thus, the argument extended as far as the definition of "human occupied." Ultimately, however, this discussion failed to clarify the basic issue of whether there is any significance, for the viewpoint of pure science or science and technology, in using HOV to conduct deep-sea research.

When the Shinkai 2000 was retired in 2004, her contribution to science and necessity of HOV was also the subject of a paper.[5] As reasons why HOV are necessary, one of the authors made the following arguments based on his own experience in dives. Firstly, he cited the acuity of the human eye, noting that it is impossible to reproduce the capabilities of the human eye with current technology. Secondly, he mentioned "intellectual curiosity," in other words, the notion that science will not progress without a thirst for knowledge. As 3rd and 4th points, he also mentioned a "feeling of presence" and the importance of the researcher's intuition. While these are undoubtedly essential conditions for scientists, we must also ask how important they actually are for progress in deep-sea pure science and science and technology. Many marine researchers hope to do research aboard HOV, and it is obvious that trouble in the current HOV would impede marine research. However, even if these researchers hope to see new HOV built, they themselves are not responsible for the building. Without a development budget, manufacturers cannot build these vehicles, and as time passes, it becomes difficult to maintain the technologies necessary for building.

Japan's Third Science and Technology Basic Plan mentioned "Development of human occupied submergence vehicle" as one national critical technology,[6] but, at present, this has not been adopted in next-generation deep-sea research technologies by the Ministry of Education, Culture, Sports, Science and Technology (MEXT).[7]

However, the time will soon come when Japan must consider whether HOV are necessary for humankind or not. While it may undoubtedly be true that deep-sea research is necessary for humankind, the question is whether HOV are necessary for Japan, and if so, is it necessary to develop new building technologies. In other words, is the form of HOV used to date adequate, and if not, what form should a new, next-generation HOV take? It is not too early to begin study of these fundamental questions.

Moreover, when the present generation of HOV was developed, built, and put into service, the technology for unoccupied vehicles was still immature. In recent years, the background of this argument has changed significantly as a result of the active use of unoccupied vehicles in deep-sea environments and remarkable progress in technical development. Because occupied and unoccupied vehicles have respective strengths and weaknesses, the division of roles must be clarified from the viewpoint of technical development and operation. A similar debate is also underway in the United States.[8]

This article considers trends in the development of deep-submersible HOVs in the United States and China and proposes the future direction for Japan to take. It would be too easy to say that Japan should develop a new HOV simply because other countries are doing so. Therefore, in this report, the author would like to review the evolution of HOV and examine the proper direction for Japan with regard to a next-generation HOV referring to this history.

2 Challenging the depths: An historical perspective

2-1 Nothing at abyssal depths?

Historically, humankind only recently acquired the ability to observe scientifically the underwater world.[9] Until the invention of the aquarium in England in the mid-19th century, pictures of sea life had, almost without exception, depicted either fish and whales swimming at the water surfaces, or desiccated bivalves, conchs, and other mollusks lying on beaches.[10] We could not begin to imagine the kinds of creatures that actually live in the world's oceans. Few if any believed that living organisms could exist at abyssal depths, and it was inconceivable that ocean floor crust is born in the abyssal fissures.

Until the middle of the 19th century, it had been thought that life could not exist in deep seas due to the extreme high pressure and utter darkness in such regions. However, dredging of the ocean floor using a tool attached to the end of a long chain revealed an astonishing variety of life. At the end of the 19th century, the English warship Challenger made a voyage which applied the scalpel of science to the deep sea for the first time, and discovered deep-sea life and manganese nodules. At the beginning of the 20th century, the great powers of Europe carried out marine research, laying the foundations for marine science which led to the present. From around the Second World War, science and technology, exemplified by underwater acoustic technology and electronics, were applied to marine research, particularly in the United States, and marine science entered a period of rapid progress.

2-2 Origin of "deep-submersible vehicles"

In 1930, the American biologist William Beebe descended to a depth of 428m in a steel sphere 1.4m in diameter (called a bathysphere) suspended from a wire rope. Beebe was the first human to observe fish and other diverse forms of deep-sea life with the naked eye. In 1934, he descended to a depth of 908m. However, the sphere itself weighed 2.5 tons, and even adjusting for buoyancy, it was necessary to suspend a weight of 1t from the wire. Thus, there was a constant danger that the wire might break, and the underwater observer was unable to move freely in the water. The HOV of this period is termed the "0 generation."

The "1st generation HOVs" were developed in response to the challenge of creating a maneuverable vehicle. In 1947, the Swiss physicist Auguste Piccard, who is known as the first person to reach the stratosphere in a balloon, invented the bathyscaphe (literally, "deep boat") based on the same principle as the balloon. To secure buoyancy in a pressure sphere (diameter: 2m) carrying a crew of two persons, the pressure sphere was mounted under a tank containing a large amount of gasoline. This 1st generation submersible maneuvered underwater using thrusters (propellers for movement). Applying this technology, the U.S. Navy built a 10,000m class bathyscaphe called the "Trieste," which set a record for a 10,906m dive in the Challenger Deep in the Mariana Trench. The crew for this memorable dive consisted of Auguste Piccard's son, Jacques Piccard, and Don Walsh of the U.S. Navy. The French Navy also built a similar bathyscaphe called the Archmede, which made dives in 1962 to a maximum depth of 9,545m in the Japan Trench and Kuril Trench. Tadayoshi Sasaki of Hokkaido University, who was a crew member on these dives, observed a continuous shower of organic detritus that had formed near the ocean surface sinking to the sea bottom, and named this phenomenon "marine snow."

Bathyscaphes, which enable relatively free movement underwater, require more than 100m^3 of gasoline, including an allowance for surfacing, and as much as 75t of buoyancy material for the 4t hull. The weight of the submersible in air exceeds 80t, making handling difficult and dangerous and maneuvering underwater relatively unresponsive. However, in spite of its slow movement, the fact that this submersible is capable of 10,000m class deep dives is a strong point of the 1st generation HOVs.

2-3 Period of development in deep-sea research

The 2nd generation of HOV was developed giving priority to underwater maneuvering performance. The basic technologies in this generation centered on the development of buoyancy materials, lightening of the pressure hull housing the crew, improvement of the power supply for underwater navigation, and establishment of safety measure technologies. Descent/ascent of HOV is controlled by adjusting the weight of the vessel in the water. Fundamentally, the vessel is manufactured to be heavier than seawater, and is then made lighter than seawater by attaching a large amount of buoyancy material. The vessels are loaded with weights, or ballast, to enable descent. At the sea bottom, a condition of neutral buoyancy, in which the vessel neither sinks nor rises, is achieved by releasing some of the ballast, and the vertical movement necessary for work is achieved using the force of the thrusters. When work is completed, the remaining ballast is released, allowing the vessel to surface. During this period, the buoyancy material must resist crushing regardless of the circumstances.

The 1st generation Alvin was built in the United States in 1964. At the time of building, its maximum depth was 1800m. For the buoyancy material, syntactic foam was developed as a replacement for gasoline. This is a molded material in which glass micro-spheres with a size of several 10μm are embedded in resin. A small-scale, lightweight submersible with a weight on the order of 15t was developed, making it possible to transport the submersible to the intended destination on a dedicated mother vessel rather than by tugboat, as in the conventional practice. This established today's operating practice in which the submersible was launched/recovered at the site.

This technical development greatly expanded the operating range and improved the operational efficiency of the HOV used in scientific research. To date, 2nd generation HOVs include the original Alvin in the U.S. (maximum depth: 4,500m, operated by the Woods Hole Oceanographic Institution), Japan's Shinkai 2000 (2000m class; taken out of service and retired in 2004) and Shinkai 6500 (maximum depth: 6500m; operated by the Japan Agency for Marine-Earth Science and Technology:JAMSTEC), France's Nautile (6000m class; operated by the French Research Institute for Exploitation of the Sea:IFREMER), and Russia's two Mir submersibles (6000m class).

In this generation of HOV, the focus shifted from competition to achieve the greatest depth to scientific research and investigation of resources. Because a maximum depth of 6000m enables scientific research covering 95% of the world's oceans and manganese nodules, which are considered a promising resource for future development, are found at depths of 4000-6000m, the maximum depths of many submersibles has been set at 6000m (Figure 1).

Table 1 presents an outline of the performance of the world's main deep-submersible HOVs in active use at present. Japan's Shinkai 6500 was built in the 1980s, which was a period when several countries were actively developing 6000m class HOVs.[11] Although HOV of this class had been proposed in the 1970s, the risk of moving directly to the building of a 6000m

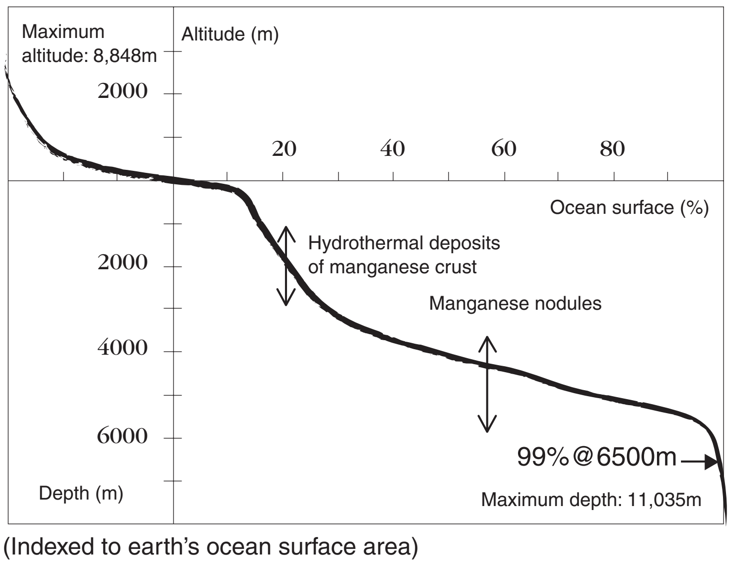


Figure 1 : Distribution of earth's altitude/depth and range of distribution of seafloor mineral resources

Table 1 : World's main human occupied vehicles (HOV)

Vehicle (country)	Alvin (US)	Nautile (France)	Mir 1 & 2 (Russia)	Shinkai 6500 (Japan)
Maximum depth [m]	4,500	6,000	6,000	6,500
Ocean coverage [%]	62%	98%	98%	99%
Dives/year	180	100-115	Irregular (low frequency)	60
Researchers/pilot	2 / 1	1 / 2	Total 3	1 / 2
Bottom time [hr]	4~5	5	10 ~ 15	4
Payload [kg]*	680	200	250	150
Sphere volume [m^3]	4.07	4.84	4.84	4.19
Observation directions	Side/down	Front/center	Front/center	Side/down
Year built	1964	1985	1987	1987

*Payload: Total weight of equipment carried aboard by researchers for scientific research and samples taken during dive.

class vessel using unproven technology was considered unacceptable. First, therefore, Japan developed and built the Shinkai 2000 in order to establish the building technology and navigation technology. Based on the know-how obtained with the Shinkai 2000 and progress in related technologies, beginning with the manufacture of titanium pressure hulls, the Shinkai 6500 HOV, with a maximum depth of 6500m, was developed and built in the 1980s and put into service in 1990. Research dives began in 1991. A variety of the most advanced technologies of the time were incorporated in the Shinkai 6500 to ensure safe navigation, including acrylic resin viewports[12] which enable the pilot and researchers to view the sea outside the pressure hull, an underwater telephone system that allows communication between the deep sea and mother ship on the surface, and an acoustic observation sonar system for locating obstacles underwater, where visibility is limited to only about 10m.

2-4 Achievements of deep-submersible HOVs

Operation of 2nd generation deep-submersible HOVs resulted in numerous achievements in pure science and science and technology.

In the field of resource surveys, hydrothermal deposits had been discovered successively along the mid-oceanic ridge in the Pacific Ocean, but no similar deposits had been found in the Atlantic mid-oceanic ridge. However, in 1986, scientists aboard the Alvin discovered hydrothermal deposits in the TAG ocean area*1 on the Atlantic mid-oceanic ridge. In 1991, Russian and American scientists aboard the Russian HOV Mir discovered the largest scale hydrothermal deposit in the Atlantic, which they named Mir. Following this, a large number of other hydrothermal deposits were also discovered. On the other hand, in research on deep-sea life, in 1992, a Japanese scientist aboard the Shinkai 6500 discovered whale bones with adhering shells and shrimp at 4146m in the Torishima area. In 1994, Russian scientists discovered a large number of hydrothermal organisms in the Atlantic Ocean, and in 1995, Japanese researchers discovered deep-sea chemotrophic life forms in the Okushiri-oki area (off Okushiri Island near Hokkaido, northern Japan). In deep-sea geology, the Shinkai 6500 discovered a fissure on a sloping surface at 6200m in the Japan Trench.

HOVs have also responded to a number of emergencies. For example, in 1966, the 1st generation Alvin successfully recovered a hydrogen bomb which had been lost by the U.S. military at a depth of 914m off the Spanish coast. Following the Challenger space shuttle disaster in 1986, three HOVs and one unoccupied vehicle recovered a 50t fragment of the shuttle, and in 1989, the Mir sampled sea bottom sediments and measured radioactivity after the sinking of the former Soviet Union's nuclear submarine Kursk, and carried out work to seal the ship's bow in order to prevent leaks of radioactivity.

3 Development trends in HOV in the United States

3-1 Future plans for deep submergence science in the U.S.

In 2004, the U.S. Committee on Future Needs in Deep Submergence Science issued a report on "Occupied and Unoccupied Vehicles in Basic Ocean Research."[8] The report summarized how the United States as a nation should direct its future efforts in research on deep submergence science*2, and examined the proper form of deep submersibles, including the necessary human occupied and unoccupied vehicles. Subsequently, in accordance with the recommendations of the Committee, the U.S. began development of a successor submersible to the current Alvin as an HOV, and is also developing an 11,000m class hybrid as an unoccupied vehicle. This hybrid will be a vehicle combining the two modes of remotely operated vehicle (ROV) and autonomous underwater vehicle (AUV).

The above-mentioned Committee was established at the request of the National Science Foundation (NSF), representing scientific research, the National Oceanic and Atmospheric Administration (NOAA), representing marine research projects, and the U.S. Navy. The Committee's study objectives were to evaluate the future image and required equipments for deep submergence science, and to evaluate the feasibility of technologies supporting basic research in deep sea and seafloor areas. The concrete content studied comprised the following items:

(1) valuation of the performance of occupied and unoccupied vehicles currently in use or under study.
(2) Recommendations on integrated use of research equipment for ongoing implementation of world standard deep submergence scientific research.
(3) Study of innovative design concepts and new technologies which should be incorporated in research equipment in order to meet future research needs.

The following four recommendations were presented as a result of study of the development of new vehicles.

(Recommendation 1)

The NSF's Division of Ocean Sciences should build a new unoccupied vehicle for use in scientific research. This will increase the number of deep submergence vehicles contributing to the research activities of a large number of users in diverse research fields and marine geographies.

(Recommendation 2)

The NSF's Division of Ocean Sciences should study the distribution of new unoccupied vehicles so as to minimize the movement time required for periodic inspections and improvements of new and current unoccupied vehicles.

(Recommendation 3)

Unoccupied vehicles are the optimum alternative for investigation of the ocean floor. Considering cost and risk, HOV cannot be used in research at depths greater than 6500m. However, manned research is key to national oceanographic research, and HOV enable direct observation. The current Alvin is inadequate for many of the requirements of scientific research. Accordingly, the NSF's Division of Ocean Sciences should build a new type of HOV with improved functions. (Improvement of functions means improvement of field-of-view performance, expansion of the neutral buoyancy control function and scientific payload, extension of time at working depth, etc.)

(Recommendation 4)

Accordingly, if a new HOV capable of diving to great depths (exceeding 6000m) is to be built, this should be limited to cases in which it can be demonstrated, in the design stage, that there will be no large increase in cost or risk.

3-2 Policy for building of new type HOV

Based on the recommendations in the above-mentioned Committee on Future Needs in Deep Submergence Science, the United States will study concrete policies for the building of a new type of HOV. Before arriving at its recommendations, the fact that a new type of HOV had been studied since 1999, centering on the Woods Hole Oceanographic Institution, was explained in detail. In this process, an 11,000m class all-depth HOV capable of diving to the deepest ocean depths on the planet was also studied. However, it became clear that building of such a vehicle was impossible within a timeframe of several years and with the limited budget available, and because the weight of the submersible would far exceed the capacity of current mother ships (because weight increases by a corresponding amount when the pressure is double that of the 6000m class). Furthermore, the possibility of manufacturing buoyancy materials, batteries, and electronic devices which would retain their integrity at this depth was unclear. Whether human beings could withstand such depths was also unknown. Even assuming that all these conditions could be met, the lack of testing equipment to verify this fact was also a problem. For these reasons, the all-depth HOV was excluded from study. On the other hand, a proposal to improve the current 4500m class Alvin to the 6000m class was also examined, but it was concluded that the improved submersible would not adequately satisfy the needs of deep submergence science. Finally, therefore, this study recommended a new type of HOV that could be built within the budgetary limitations. The following five items were recommended as specific functions which should be incorporated in the new type of HOV.

a) Improvement in the performance of the variable ballast device: In order to conduct research while hovering at intermediate depths, continuous adjustment of the balance of buoyancy and weight must be possible; this is the most important issue for a new type of HOV.

b) Development of a non-mercury attitude control system (trim system): In the current Alvin, attitude is controlled using a mercury-type system; however, for environmental reasons, use of mercury is undesirable.
c) Electronic devices/tools compatible with a 7000m class new type unoccupied vehicle: This is important for commonality between platforms.
d) Use of optical fiber cable: Continuous data transmission from the HOV (status of research, transmission of video images to other researchers, maneuvering data, etc.) should be possible; use of optical fiber cable is also necessary in order to control cameras and other equipment from the ship.
e) System for designating targets for video cameras on ship: This system should enable designation, positioning, and tracking of target objects by tracking eye movements.

Next, the pressure hull carrying the crew was studied. This is an important item for the cost evaluation of the new type of HOV. The current Alvin in the U.S. was built in the 1970s, and the U.S. no longer possesses the equipment and welding techniques necessary to manufacture the titanium spherical pressure hull used in that vehicle. At the present point in time, only Russia and Japan possess the necessary technologies. Improvement of the pressure hull of the current Alvin was also studied. From the viewpoint of cost, this is the most realistic alternative. However, the diving depth would be limited to the current 4500m, and there was also concern that capabilities would be substantially reduced from the present level. Based on this study, building of a new titanium hull was considered a desirable alternative for improving the scientific research capabilities of the vehicle, for example, by increasing the maximum depth, changing the position of the window, etc. However, after further study and evaluation of manufacturing technology and cost, it was concluded that an HOV with a maximum depth of 6000m or more should be built, provided that manufacture appeared possible.

3-3 Specifications and technologies of new Alvin

Various organizations involved in ocean science and other interested parties in the U.S. had studied the necessity of HOV since 1999. Finally, in 2004, the researchers at the Woods Hole Oceanographic Institution proposed a 6500m class submersible as an alternative to the Alvin.[13,14] It can be thought that the plan to replace the Alvin with a new 6500m class submersible was adopted not only due to a desire to upgrade the research capabilities of the current Alvin, but also as a response to the retirement of the 6000m class submersible Sea Cliff (1984), which had been operated by the U.S. Navy.

Table 2 shows a comparison of the specifications of the new Alvin and the current Alvin. Figure 2 shows the assumed appearance of the new submersible. The design issues and results of conceptual design of the new Alvin are discussed in the following sections (1) through (8).

(1) Maximum depth

Maximum depth is the most important design parameter. In the United States, the debate on this issue was similar to that when Japan studied the Shinkai 6500, and the target depth was ultimately set at 6500m, as this makes it possible to reach 99% of the planet's ocean floor. Likewise, where technical limitations are concerned, lightweight buoyancy materials which can be used with confidence to 6500m are available, but at greater depths, the specific gravity of the buoyancy materials increases and the size and weight of the submersible increases significantly. As problems, this reduces maneuverability and makes it impossible to use the current support ships.

(2) Pressure hull

The pressure hull carries a pilot and two researchers, and must provide space for maneuvering of the submersible, observation, operations involved in taking samples, and the like. Therefore, the capacity of the submersible was increased by enlarging the diameter of the current Alvin 6.3%. This improves livability and secures space for internal electronic devices and equipment carried into the vehicle.

Several materials were reportedly studied for the spherical hull. Superhard maraging steel, which was used in Russia's Mir submersibles, is a cast steel with a high content of nickel. Its

Table 2 : Comparison of specifications of the new Alvin and current Alvin

	New Alvin	Current Alvin
Operating depth (ocean coverage)	6500m (99%)	4500m (63%)
Dimensions (L*B*D)	ND (smaller than existing Alvin)	7.3 * 2.6 * 3.7m
Weight	18 ton	17 ton
Sphere material	Ti 6 Al 4 V-EL I	Ti 621/ 0.8 Mo
Sphere inner diameter/volume	2.10m /4.84m^3	1.98m /4.07m^3
No. of viewports	5	3
Crew	Pilot: 1, researchers: 2	Pilot: 1, researchers: 2
Underwater operating time	10.5H	9H (approx.)
Propulsion system (thrusters)	Forward/reverse, vertical: 2; horizontal: 2	Forward/reverse, vertical: 2; horizontal: 1
Speed (forward/reverse)	3 kt	2 kt
Speed (vertical)	44 m/min	30 m/min
Trim angle	±15°	±7.5°
Payload	181 kg	125 kg
Positional control	Automatic position/azimuth control	Manual & azimuth control
Battery capacity	115kWh (approx.)	35 kWh
Descent/ascent method	Seawater ballast	Iron drop weight

strength is comparable to that of titanium, but as a drawback, it is susceptible to corrosion in seawater. The 611 titanium used in the U.S. submersibles Alvin and Sea Cliff are not generally used at present. Finally, the 6-4 titanium used in Japan's Shinkai 6500 and France's Nautile was selected. (Ti6Al4V-ELI: This material is an alloy containing 6% aluminum and 4% vanadium; ELI (extremely low interstitial) relates to the extremely low oxygen content, which secures excellent weldability.)

The number of viewports was also increased from the conventional three to five. The three windows on the forward side are arranged in close proximity so the pilot in the center and researchers on the right and left sides share a common field of view. The two windows on the sides allow the pilot to see to the sides without interfering with the researchers, enabling safe maneuvering without sacrificing observation.

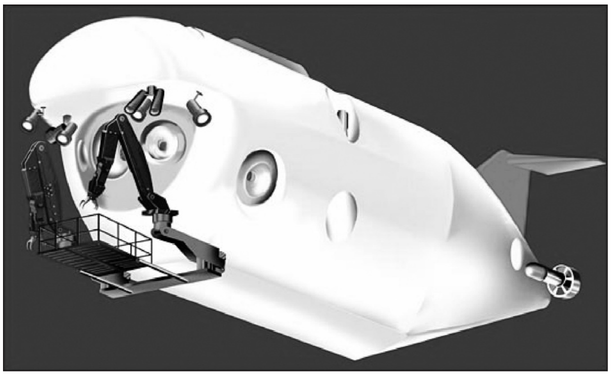


Figure 2 : An artist's conceptual drawing of the New Alvin (US)

From the Woods Hole Oceanographic Institution homepage, May 7, 2007.

(3) Buoyancy material

Buoyancy material is an essential component for securing the buoyancy of the submersible in the deep sea, and is also a controlling factor determining the weight and size of the submersible. The specific gravity of the buoyancy material used in the current Alvin is 0.577, but this was considered too large for the new submersible. The buoyancy material developed for use in unoccupied vehicles has a specific gravity of 0.481 and was the lightest weight material which could be used at a depth of 6500m at the time of the study. Subsequently, development of a buoyancy material with a specific gravity of 0.481 was completed, and further weight reduction is being attempted.

(4) Variable ballast

Ballast refers to water or other substances which are loaded on a ship as weight to improve stability. HOVs also use a variable ballast system in which the weight of the vessel is adjusted by controlling the amount of water in the ballast tanks. Ballast control as three object functions: (a) To secure the weight and buoyancy necessary for descent and ascent, respectively, (b) to compensate for changes in weight when samples are taken during a dive, and (c) to adjust the trim angle in order to increase the rate of ascent or descent. ("Trim" is the bow-to-stern inclination, or attitude, of the submersible.)

Ballast tanks are manufactured in the form of titanium spheres in order to withstand the external pressure at a depth of 6500m while maintaining an internal pressure of 1atm. The submersible begins the dive with its ballast tanks filled with the prescribed amount of seawater. During the dive, seawater is discharged or taken in as required by two pumps. This makes it possible to stop the submersible at arbitrary intermediate depths and conduct observations. A trial calculation has shown that the rate of descent/ascent is 30m/min with a trim angle of 15° and 45m/min at 25°. Assuming a descent rate of 45m/min, it is possible to reach an ocean floor with a depth of 6500m in 2 1/2 hours. It may be noted that the trim angle of the submersible is not adjusted using the ballast alone; it is also possible to move the batteries and weights forward or aft in order to control trim. This weight can also be jettisoned in the event that emergency surfacing is necessary.

(5) Propulsion system

The submersible is equipped with an advanced propulsion system which enables forward/reverse and lateral movement. The propulsion system comprises a total of six reversible electric thrusters. Two thrusters are provided at the stern for forward/reverse movement. For lateral movement and turning, one horizontal thruster is installed at each of the bow and stern, and for vertical motion, one vertical thruster is installed each at the right and left sides. It is possible to maintain the designated position and orientation, depth, and attitude by manipulating these devices. The position maintenance and maneuvering system using these thrusters is the same as that developed for unoccupied vehicles.

(6) Power supply

As the power supply, lithium ion batteries were considered the optimum choice from the viewpoint of energy density and life. Among these, attention was focused on lithium-polymer batteries, as these can be housed in an oil pressure-equalizing vessel. This type of battery has been used in autonomous intelligent underwater vehicles and is considered to have a life of more than 5 years. Fuel cells were excluded from study, as this technology is considered to be in the developmental stage.

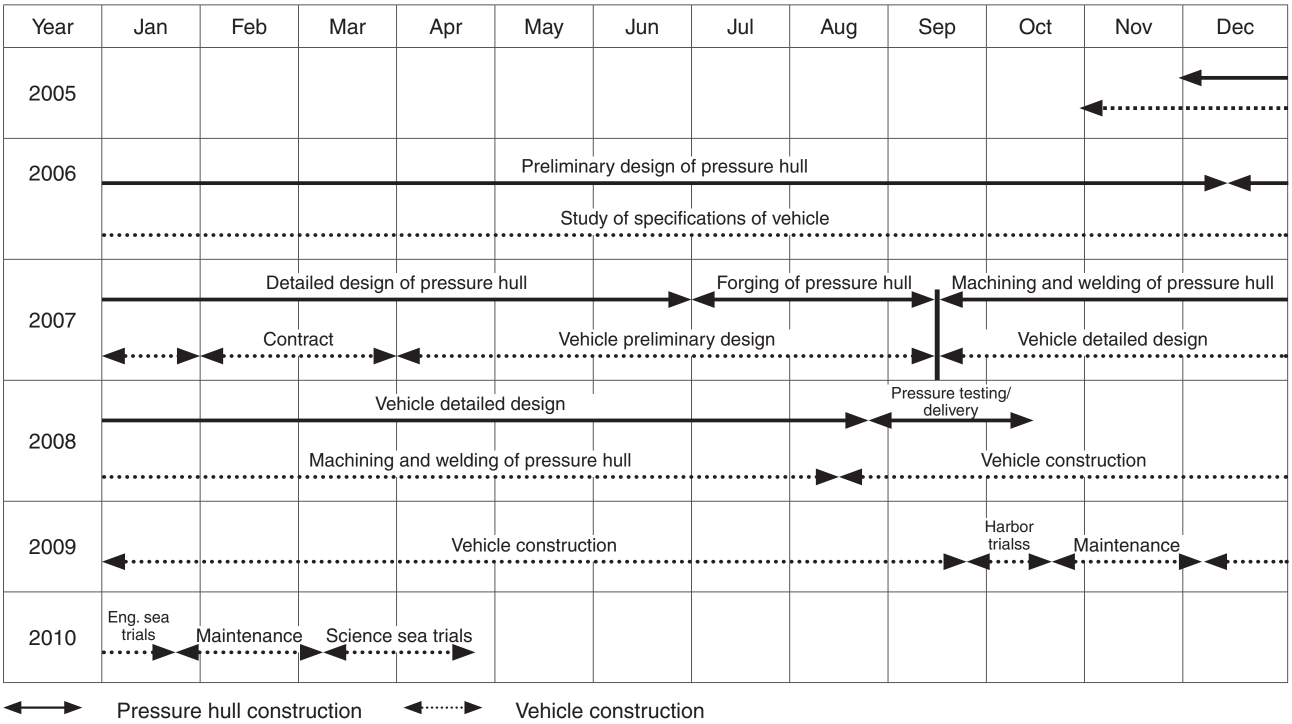
(7) Safety measures

Safety measures comply with U.S. ship classification rules. Provisions include manipulators and weights that can be jettisoned in case of emergency, minimization of the risk of entanglement, improvement of the life support capacity, and others. Because the new submersible employs the variable ballast system in descent/ascent, jettisonable weight for emergency surfacing is provided as a safety measure in case of failure of the ballast system pumps or batteries, and adequate buoyancy is secured. A device for emergency recovery of the submersible is also provided on the supporting mother ship.

(8) Scientific research equipment

Power for the manipulators and various scientific research equipments is provide by a hydraulic system rated at 20.7MPa × 9.5l/min, realizing an improvement of more than 90% in comparison with the performance of the current Alvin. The new submersible has two manipulators, which are mounted on extensible bases. A large sample basket is provided in the center, and rotatable baskets are provided on the vessel's two sides. The TV camera system comprises two high resolution cameras with zoom which can be controlled by the two observers, making it possible to obtain high quality video images. Panoramic TV camera and compact camera mounted on the manipulators are also equipped. Lighting is provided by a combination of high output HMI lights and compact xenon lamps. As an advantage of the xenon lamps, these devices can be turned on and off without warm-up and thus provide a high degree of freedom. For observation under the

Table 3 : Schedule for replacement HOV update in US (as of Sept. 25, 2006)



Prepared by the STFC based on Reference [15].

vessel, the submersible is equipped with sonar for research on seafloor.

The submersible and supporting mother ship communicate by means of an audio modem. The modem has a transmission rate of 7000bps and can transmit a standard quality jpeg image in 8 seconds. When an image is received on the mother ship, the compressed data are decompressed by a dedicated computer and can be used on the ship-board network. The submersible and mother ship are also joined by a small-diameter optical fiber cable, enabling real time communication between them. This allows scientists on the mother ship to participate and cooperate in research. Assuming use of satellite communications, participation from land will also be possible, enabling use of marine research in education, etc. This is also expected to be used to promote public understanding of science and technology.

3-4 Building schedule of new Alvin

Building of the new Alvin began in the fall of 2005 and entered the transition stage from Phase 1 to Phase 2 in the fall of 2007. Work in Phase I included design of the pressure hull and basic design of the boat hull. In Phase 2, the makers responsible for building will be decided and work on the pressure hull will move to fabrication, welding, and pressure testing, while hull-related work will move to detailed design and construction (Table 3).

3-5 Position of HOVs in the U.S.

The United States has established a basic policy of comprehensive operation of HOVs and unoccupied ROV/AUV for research in deep-sea science, and is implementing plans for development and building along these lines. As an HOV, a 6500m class new Alvin will be built, and as an unoccupied vehicle, an 11,000m class hybrid system will be developed. Depending on the purpose of the investigation, the unoccupied hybrid system will have an autonomous-type intelligent underwater robot mode for wide area mapping, etc., and a remote control-type unoccupied research mode for use when detailed, pinpoint research is necessary.

In the development of unoccupied submersibles, the U.S. is undertaking the challenge of new technologies such as use of seamless ceramic hollow balls as buoyancy material. However, the HOV is being built as a synthesis of conventional deep-submergence science and technology. As the reason for this, the U.S. is developing an HOV and unoccupied vehicle in parallel, and in particular, time and budgets leave no room for the development of new technologies for the HOV. There will be no feedback of new technologies obtained in the development of the unoccupied vehicle to the HOV.

Where this point is concerned, although the new HOV now being built in the U.S. will have the capability to investigate ecosystems while hovering at intermediate depths, and will enable comparatively rapid diving and surfacing, the basic concept does not represent an advance beyond the 2nd generation.

4 Trends in the development of HOV in China

4-1 Outline of 7000m HOV

An article distributed by China's Xinhua News Agency on February 2, 2007 announced that China will launch an independently-developed 7000m HOV in 2007 (Figure 3). This project is being carried out as part of the National High-Tech R&D Program (commonly known as the "863 Program") under the country's 10th 5-Year Plan (2006-2010). In September 2006, China announced that the submersible was already in the assembly stage. Experimental operation of the submersible at sea had been scheduled for completion within the period of the 10th 5-Year Plan. However, according to the article of Feb. 2007, "China has developed a submersible capable of covering 99.8% of the world's ocean floor, and is aiming at completion in 2008."

4-2 Performance of 7000m HOV

Although this submersible is being assembled in China, Russia was responsible for production of the pressure hull and life support system. The cost of building is put at 180 million yuan, or approximately US$25 million. The performance of the 7000m HOV is described in the following sections (1) through (5).[16]

Figure 3 : Model of China's 7000m HOV

Source: Beijing Daily, January 31, 2007

(1) 99.8% coverage of world's oceans

Table 4 shows a comparison of the specifications of China's 7000m HOV and the Shinkai 6500. The maximum depth of China's HOV is 7000m, which gives it a diving range covering 99.8% of the world's ocean floor. By comparison, the Shinkai 6500 has a maximum depth of 6500m, giving it a diving range of 98%. The hull dimensions of the Chinese vehicle are somewhat shorter and slightly broader than those of the Shinkai 6500. While its weight is slightly lighter than that of the Shinkai 6500, it is quite heavy in comparison with Russia's Mir (18.6t). Unlike the Mir, there is no equipment for launching or recovery on the broadside of the vehicle, and the size and stern arrangement of these equipments are expected to resemble those of the Shinkai 6500.

Table 4 : Basic specifications of China's 7000m HOV

	China 7000	Shinkai 6500
Operating depth [m]	7000	6500
Researchers/pilot	2/1	1/2
Total length [m]	8.2	9.5
Total height [m]	3.4	3.2
Total width [m]	3.0	2.7
Weight in air [ton]	25.0	25.8
Sphere material	Titanium alloy	Titanium alloy
Sphere inner diameter [m]	2.1	2.0
Viewport diameter [mm]		
Center: 1	200	120
Side: 2	120	120
Life support duration [H]	84	128
Maximum speed [kt]	2.5	2.5
Payload [kg]	220	200
Batteries:		
Type	Silver oxide-zinc	Lithium ion
Capacity [kWh]	110.0	86.4
Underwater working time [H]	6	4

(2) Russian-made pressure hull

The pressure hull, which will hold one pilot and two researchers, is constructed of a 6-4 titanium alloy and has an inner diameter of 2.1m. The plate thickness is 76-78mm, with deviations of ±4mm in the completed radius, and sphericity is 0.4% or less. The pressure hull of the Shinkai 6500 is a titanium alloy 2.0m in inner diameter, the plate thickness is 73.5mm, and error in the diameter is 0.5mm, giving it sphericity of 0.025%. In comparison with the Shinkai 6500, the diameter is 5% larger, but the plate thickness is only about 3% greater and sphericity is also relatively poor. This notwithstanding, the diving depth of the new Chinese submersible is 8% greater.

According to the literature,[3] the pressure hull was manufactured by a Russian maker which also manufactured the Mir 6000m class HOV (nickel steel) and a new 6000m class HOV called the Consul (titanium alloy), which was built around the year 2000. The manufacturing method for the pressure hull involves producing two hemispherical parts by TIG welding*3 6 side plates to a top plate, followed by heat treatment and polishing by machining; the two halves are then joined by TIG welding to form a complete sphere. Pressure tests were also performed in Russia, and included a 1 hour test at a water pressure equivalent to 7700m, or a 10% greater depth than the vessel's 7000m maximum depth, a continuous 8 hour test at water pressure equivalent to 7000m, and a test simulating 0-7000m ascent/descent of the submersible, which was repeated 6 times. No problems were reported in any of these tests.

The viewports in the pressure hull have a circular truncated cone shape. One central viewport with an inner diameter of 20cm and two side ports with inner diameters of 12cm are provided. The central viewport is considerable larger than that of the Shinkai 6500 (12cm), and is the same type as that used in the Russian Mir. The two side windows are arranged closer to the front than in the Shinkai 6500 and Alvin. This design has the advantage of enabling navigation while both the pilot and the scientists simultaneously observe an objective in front of the vehicle. However, safety is reduced, as it is not possible to see dangers on the sides.

(3) Smart propulsion and navigating system

In HOVs, an arrangement of several thrusters is used to move forward and turn the vehicle's head to the sides and vertically. The Chinese 7000m HOV has a teardrop shape tapering toward the stern and four tail fins which form an X shape. Four main thrusters inclined in a narrowing shape are mounted in the spaces between the four fins. Although the four thrusters are not movable, it is possible not only to move forward/backward, but also to turn horizontally and vertically, by composing the propulsive force of these four thrusters. This main thruster system is based on the same design concept as that in the Russian Mir submersibles, and is different from that used in the Shinkai 6500, which is turned by swinging the large main thrusters to the right or left. Side thrusters are also mounted on the front of the vessel's hull. One horizontal thruster is mounted on the top of the bow (same arrangement as in the Nautile and Shinkai 6500), and thrusters for vertical/horizontal turning and aiding propulsion are provided on the two sides of the hull (same as in the Mir and Shinkai 2000). Parallel movement in the horizontal direction is achieved using a combination of the horizontal thruster on the bow and the right and left stern thrusters, while vertical movement uses a combination of the bow side thrusters and the top and bottom stern thrusters.

(4) Other technologies

Silver oxide-zinc batteries are used. The battery capacity is 110kWH (110V, 800AH), which is approximately 30% larger than in the Shinkai 6500. Maximum continuous dive/working time is 6 hours, which greatly exceeds that of the Shinkai 6500. A pair of manipulators for use in taking samples from the ocean floor are mounted on the right and left sides of the vehicle. These devices have joints with 7 degrees of freedom. While it is possible to transmit images to the mother ship, the transmission rate is only 80kbps, compared to 100Mbps in ordinary internet transmissions. Thus, transmission of a color image requires approximately 30sec. A syntactic foam manufactured in the United Kingdom is expected to be used as the buoyancy material. As noted previously, this type of material consists of glass micro-spheres embedded in resin.

4-3 Significance of the Chinese HOV

The core technologies for deep-submersible HOV are a three-point set comprising the pressure hull, buoyancy material, and power supply. However, in addition to these, operation becomes possible only after integrating a diverse range of technologies related to maneuvering, observation, collection of samples, safety, and others. The most important objective in China's development of a HOV is generally considered to be acquisition of military technology. The country also appears to be planning exploration for marine resources and similar activities. Although one feels that China has little interest in contributing to marine science, future operation may have an indirect effect in this connection. As an element in technical development, this project has also given Russia an opportunity to develop a 7000m pressure hull, which significantly exceeds the 6500m class.

Regarding the technical level of the HOV, the target of achieving the world's deepest maximum depth in an 2nd generation HOV is quite obvious. However, when considering the ideal form of a next-generation HOV, there appears to be little that Japan can learn from this Chinese HOV, either in terms of pure science or science and technology.

5 Future direction of deep-submersible HOV development in Japan

5-1 History of development of deep-submersible HOVs

Japan began development of human occupied deep-submersible research submersibles around 1965.[17] In October 1963, the issue was submitted to the Council for Marine Science and Technology, and a 5-Year Plan was drafted envisioning a timeframe extending approximately 10 years into the future. Under this plan, active promotion of marine development was adopted as a national policy and the development of the marine science and technology which is indispensable as the basis for this was made a priority target. At the time, the United States was already conducting wide-ranging research and development as part of plan for development of a 6000m class vehicle. Ultimately, a 6000m submersible was not realized in the United States due to domestic circumstances. In Japan, the target depth for the submersible research vehicle was set at 6000m in response to the issue put before the above-mentioned Council for Marine Science and Technology, based on the fact that a submersible capable of reaching this depth can cover 95% of the world's oceans, and large numbers of manganese nodules, which were considered a promising resource for future development at the time, exist at depths of 4000-6000m. The necessary technical development tasks included the structure, material, and fabrication method for the pressure hull, buoyancy material, power system, position measurement system, various types of research equipment, and others. In addition, it was also considered necessary to construct a water basin for high pressure testing.

The thinking on the necessity of a deep submersible was exemplified by the following comments by the late Kenji Okumura,[18] who was involved in research and development during this period: "In marine development, a system engineering approach which integrates a wide range of science and technology is particularly important. Various types of science and devices must be developed as an optimized system for achieving a single goal. Japan has a high level of marine science, but we have not adequately investigated the science and technology in other countries. Our knowledge is slight, and we must carry out development in the future. A deep submersible will open a window on the deep sea, which is the most delayed area of marine development, and will lay the foundation for marine development in the future."

In 1970, the Japanese Marine Equipment Development Association (now Japanese Marine Equipment Association) established a "6000m Class Deep-submersible Research Vehicle Developmental Research Committee" and began joint research and development with shipbuilders over a 5-year period. This resulted in the elucidation of the mechanism of destruction of the spherical hull, which is the core technology for the development of a 6000m class deep submersible, and the establishment of design guidelines for this key component. These achievements played a major role in the subsequent development of the Shinkai 2000 and Shinkai 6500.

In the development of the Shinkai 6500, the original maximum depth was increased from 6000m to 6500m. The target depth was set at 6500m or greater based on the fact that the epicenter of the Sanriku-oki Earthquake was in an area of the Japan Trench with a depth of 6000-6500m. However, the safety factor of the pressure hull is “1.5 times dive depth + 300m,” which indicate the maximum depth of 6700m. Moreover, the standards for various types of equipment also specify a depth of approximately 6700m. Because there were numerous items which failed in pressure tests when the conditions exceeded 6500m, the maximum depth was finally set at 6500m.[19]

5-2 Operation and achievements of HOVs in Japan

One point which requires care when studying the achievements of HOVs is the fact that the achievements attributable to “manned” and those due to “HOV” still constitute a single entity. This is because “submersible research vehicle” was synonymous with “HOV” until recent years. Today, numerous unoccupied vehicles have also made achievements. Nevertheless, in observation of movement of living organisms and discovery of anomalies in the seafloor topography, it must be noted that there are many cases in which results were obtained by tracking research which depends on the scientist’s awareness of changing conditions. Furthermore, because the HOVs developed to date have been unable to hover at intermediate depths, few accomplishments have been made in this area. This is a challenge for the future.

The Shinkai 6500 made its maiden dive in June 1990. Table 5 shows main dives and results. The Shinkai 6500 has recorded many important achievements which take advantage of the world’s deepest diving capability, including the discovery of a biotic community in the world’s deepest cold seep (6374m) at the Japan Trench in the Sanriku-oki area, the discovery of a new type of barophilic bacteria adapted favorably to a high pressure environment at a depth of 6500m, the world’s first confirmation of a fissure thought to be caused by plate subduction, and others. In March 2007, it recorded its 1000th dive. Moreover, the activities of the Shinkai 6500 are not limited to the seas surrounding Japan; it has also been used in research on seafloor topography/geology and life inhabiting in the deep ocean in the Pacific, Atlantic, and Indian Oceans. The purposes of this research may be summarized in the following four broad fields.

(1) History of the planet (research on geological processes)

Today’s understanding of the planet is that oceanic plates are born at oceanic ridges and undergo subduction at trenches. The continents consist mainly of comparatively light granite and have an average height on the order of 840m. In contrast, oceanic plates are made up of comparatively black, heavy basalt and have a depth of 4000-5000m. Thus, the differences between continents and oceans are not merely topographical; structurally, the two are also completely different. Oceanic plates are underlain by the earth’s mantle. In the mantle, hot, lighter-weight substances rise as by convection, while the plates, which have cooled and become heavier, sink to the bottom of the mantle. The oceanic crust and continental crust collide, accumulating energy in the form of strain. Gigantic earthquakes occur when this energy is released suddenly. Geological processes are being elucidated by seafloor observation and research on various phenomena caused by these movements of the earth’s interior.

(2) Evolution of life

On land and in the surface layer of the ocean, solar energy and carbon are fundamental to the main life forms of both animals and plants. However, deep sea research has revealed that chemotrophic bacteria which synthesize organic substances using hydrogen sulfide and methane contained in seawater vented from

Table 5 : Main achievements of the Shinkai 6500

August 1989	Recorded dive depth of 6,572m in sea trials.
May 1991	First research dive (Okushiri Ridge, Sea of Japan)
July 1991	Discovered world's deepest cold seep community in Sanriku-oki area, Japan Trench (6,384m).
	Discovered new type of barophilc bacteria on the ocean-side slope in Sanriku-oki area, Japan Trench (6,500m).
	Discovered plate fissure in Sanriku-oki area, Japan Trench (6,270m).
August-November 1991	Joint Japanese-French research at North Fiji Basin, Pacific Ocean. • Seafloor plain of pillow lava (1,970-3,900m)
June 1992	Discovered new type of barophilic bacteria on ocean-side slope (5,118m) in Ryukyu Trench.
	Genome analysis of the new barophilic bacterium was completed in 2003; a large number of papers accompanied this discovery.
October 1992	Discovered community on whale bones off Torishima Island, Izu-Ogasawara (4,037m).
November 1992	Photographed Alviniconcha in hydrothermally active area of Mariana Trough (3,604-3,630m)
June-November 1994	Research dives at Mid-Atlantic Ridge and East Pacific Rise (MODE '94). • Photographed large-scale hydrothermal activity at TAG hydrothermal mound on Mid-Atlantic Ridge; observed large school of Rimicaris shrimp at black smoker (3,632-3,710m). • Photographed Riftia (2,634m). • Photographed scene of egg-laying by Austinograea yunohana crab at Pacific Rise (2,606-2,652m).
October-November 1995	Research dives at Pacific Manus Basin. • Photographed white smokers and gold-colored chimneys (1,708m).
June 1997	Discovered polychaetes in Sanriku-oki area, Japan Trench (6,360m).
July-September	Extended seafloor observation at East Pacific Rise (Ridge Flux Project).
1998	Research dives at Mid-Atlantic Ridge and Southwest Indian Ridge, etc. (MODE '98).
September	First dive in Indian Ocean by human occupied submersible.
October	Confirmed signs of hydrothermal activity at Southwest Indian Ridge (2,692m).
November	Discovered a new type of giant squid at Southwest Indian Ridge (1,055-5,362m).
August -September 1999	Research dives to investigate undersea volcanoes around the Hawaiian Islands. • Photographed pillow lava around Loihi seamount undersea volcano (2,460-4,821m).
December 2001-February 2002	Research dives at Southwest Indian Ridge and Central Indian Ridge.
July 2002	Research dives to investigate undersea volcanoes around the Hawaiian Islands.
October 2002	Research dives off southwest Java Island, Indonesia.
November 2003	Achieved 800th dive.
May 2004	Discovered liquid CO2 pool in sediments at Okinawa Trough (1,370-1,385m).
July-September 2004	Served as core of the Pacific Great Navigation NIRAI KANAI (NIppon Ridge Arc and Intra-plate Key processes Apprehension NAvigational Initiative) research project. • Discovered world's largest seafloor lava plain at East Pacific Rise (3,024m).
July 2005	Achieved 900th dive.
December 2005	Captured live deep-sea life in Sagami Bay (1,215m).
January-February 2006	Research dives at Central Indian Ridge; observed ecology of the scaly-foot gastropod (Crysomallon squamiferum) in deep-sea hydrothermally active environments (2,420-3,394m).
March 2007	Achieved 1000th dive.

Prepared by the STFC based on Reference [20].

the earth's interior, with almost no dependence on solar energy, inhabit the deep sea bottom, and an ecosystem has formed based on these microorganisms. Investigation of these deep sea ecosystems is helping to elucidate the origins of life and the process of evolution.

(3) Exploitation and preservation of deep sea life

Sustainable use of deep sea biological resources as a solution to food shortages that humankind may face in the future and research on the genetic resources available in deep sea life with diverse physiological functions are considered increasingly necessary.

(4) Thermal and material cycles

Because the history of environmental changes affecting the planet, including climate change, changes in ocean weather patterns, and similar phenomena is recorded in the various substances deposited in the ocean floor, research is being carried out to collect and decipher this record. Heat and materials released as a result of sea bottom hydrothermal activity have a significant influence on the global environment, and have been concentrated as mineral resources. Research and results will also be important in the future from the viewpoint of elucidating global environmental changes and exploiting sea bottom mineral resources.

In terms of operational frequency, the U.S. submersible Alvin has made more than 4000 dives since it was first launched in 1964, and thus averages more approximately 100 dives per year. In comparison with this, the Shinkai 6500 makes fewer dives, averaging 60 per year, or a total of 1000 dives in its career to date. This difference is mainly attributable to the cost of operation and differences in thinking on safety risk. When increased priority is given to safety, the cost of dives also increases. The fact that the Shinkai 6500 has accomplished 1000 dives under these conditions without a serious accident is due to constant, unstinting maintenance and management efforts. This kind of technology and know-how are not the result of individual academic results or manuals, but rather, require a deep understanding gained through the accumulated achievements of an organization.

5-3 Conceptual proposal for the 3rd generation of deep-submersible HOV

Japan's Shinkai 6500 has made a large number of research achievements as a 2nd generation deep-submersible HOV. However, 20 years have now passed since its building.

To date, numerous functional improvements have been made in the Shinkai 6500 responding to the research needs of scientists. For example, Ag-Zn batteries were originally used, but because it was necessary to suspend operation for maintenance, these were replaced with maintenance-free, long-life lithium ion batteries, which also reduced operating costs. The TV cameras mounted outside the vehicle as research equipment have been replaced with the CCD type, resulting in improved image quality and reduced weight, while the lighting system used to illuminate research objects has been improved by replacing the original halogen lamps with metal halide, reducing power consumption. A large sample basket has been adopted, increasing sample capacity. A system for transmitting images from the submersible to the mother ship was developed and installed, and it is now possible to give research instructions from the mother ship. However, in spite of these partial improvements, the submersible as a whole is based on a design that is now 20 years old, and the likelihood of accidents due to aging may also increase in the future. Thus, the time has now come when Japan must begin study of a new submersible.

However, it is not possible to move immediately to research and development on a submersible. A period of several years is necessary both in planning, which must be based on the experience obtained in research and development and operation to date, and in the actual building of the vehicle. The United States began building of a replacement for the Alvin 3 years after the start of study. Two years have now passed since building began, and completion is expected to take another 3 years. Reasons for the delay in planning are not limited to technical issues; in many cases, the development budget is also a factor. This is a common problem worldwide.

The author would like to suggest the following keywords for a next-generation deep-submersible HOV. Based on the development of HOVs and unoccupied research vehicles to date, the desires of scientists, and other requirements, the following four keywords may be proposed: "high speed diving/surfacing," "ability to hover at arbitrary intermediate depths," "long dive time," and "system with unoccupied research vehicles."

First, an adequate response to marine/earth science and marine development needs may be possible in the future with a maximum depth of 6000m. With the current technology, it takes approximately 2 hours to reach a depth of 6500m. Thus, the lost time in descent/ascent account for half of the possible dive time. This is a problem not only from the viewpoint of research efficiency, but also the researchers' comfort. A vehicle that can shorten this time by diving and surfacing at high speed is desirable. At present, however, time is required because the vehicle does not use its propulsion system in descent or ascent, but rather, dives by sinking naturally due to its own weight, and surfaces slowly employing buoyancy. To achieve high speed diving and surfacing, it will be necessary to use propulsion, but this will require large capacity batteries or the development of a new power source. This is perhaps the core technology for extending research time. Furthermore, the current deep research vehicles use their own heavy weight to dive, and then carry out research activities in a state of neutral buoyancy at the seafloor. This is adequate for research on seafloor topography/geology and life. However, most large marine life inhabits the intermediate depths. To carry out research on this life, it must be possible to remain static and conduct tracking research for extended periods of time. In its new HOV, the U.S. has adopted a variable buoyancy system which will enable research and measurements at intermediate depts. In comparison with the conventional method of controlling buoyancy by jettisoning iron shot, this will prevent environmental damage in the research area while also improving ascent/descent and attitude control capabilities.

The current HOVs, which are considered to be 2nd generation vehicles, must carry a human pilot as well as scientists. This is because these vehicles were built in a period when technical progress was still inadequate, and the majority of technologies involving perception, judgment, and control depended on the capabilities of human beings. Today, however, unoccupied research vehicles, including autonomous intelligent underwater vehicles, have been developed and are in operation, and advanced recognition tools and control technologies have evolved. The safety risk of these unoccupied research vehicles is far lower than with HOVs, and engineers have taken on the challenges of applying pressure resistant materials, such as buoyancy materials, and fuel cells, and developing new control systems. Naturally, the results of this development can also be applied to HOVs.

Because independent movement has been fundamental to HOVs to date, all necessary functions must be incorporated in the submersible itself. However, a next-generation submersible may perform underwater research as part of a "fleet," accompanied by a number of unoccupied vehicles with respective characteristic functions. For example, the lighting and refueling functions could be assigned to separate vehicles. As advantages of this system, if objects are illuminated with lights from the HOV itself, the field of view is poor due to reflection from suspended solids in the water, but visibility can be improved if an autonomous underwater vehicle is used to provide auxiliary lighting. A dedicated autonomous vehicle could also be used to replenish the HOV's fuel, eliminating the need to install all power supply batteries on the HOV. More efficient deep sea research will be possible if research activities can be carried out safely and efficiently while communicating with and controlling these devices. To date, the necessity of HOVs has been argued mainly from the viewpoint of the division of roles among human occupied and unoccupied vehicles and autonomous intelligent underwater vehicles. However, for the further development of deep sea research, the aim should be to develop a collaborated/integrated system of occupied and unoccupied vehicles in which their roles are divided based on the functions of each device.

6 Concluding remarks

It is generally recognized that modern science began with Newton's discovery of the law of universal gravitation.[21] However, Newton's predecessors discovered and accumulated the various facts that led to this discovery. The individual facts that the earth revolves around the sun, the moon revolves around the earth, and apples fall to the ground from trees were all known before Newton's discovery. Then, one evening in the fall of 1665, when Newton was walking around in an apple orchard near his house, an apple happened to fall from a tree. When he looked up, wondering from which tree the apple had fallen, he found the moon in the sky beyond the apples. In that instant, both the moon and apple were thought to have joined in Newton's mind. If apple falls straight toward the center of the earth, he wondered, why doesn't the moon also fall? His answer to this question was the integrated theory of universal gravitation.[22]

Science includes the tireless accumulation of large numbers of facts and phenomena, as well as individual hypotheses and theories, but science progresses through innovations, by proposing new theories which explain these facts in an unified manner, and verifying predictions based on these new theories. Continuing to provide advanced science and technology which will make it possible to train the outstanding scientists who can do this and thereby propose new paradigms should be the national responsibility.

Human occupied submersibles have played enormous roles in deep sea sciences. The fact that the deep sea is the largest biosphere on the planet has gradually become clear by the research using HOVs. In the future, this kind of research may result in new discoveries, not only through the use of HOVs alone, but by research with remotely operated vehicles, autonomous underwater vehicles, and other new technologies. Moreover, it will be necessary to develop a variety of science and technologies in parallel and to use these in combination, not only in the search for mineral deposits and bio-resources in the world's oceans and at the ocean floor, but also in order to elucidate the meaning of the deep ocean in earth science.

There are some engineering researchers who assert that it is not necessary for humans to descend into the deep sea because it would be able to develop unoccupied vehicles equipped with high performance TV cameras which are adequate for research. This, they say, is the mission of technical development. However, what is seen through a camera lens and what can be seen directly with the human eyes are not perfectly identical. For the science, it is important to clearly view what the researcher sees while also adequately tracking the object of research. Of course, humans cannot travel to the far reaches of space or observe the microscopic world with the naked eyes. For this, it is necessary to develop telescopes or microscopes. This is how science has progressed. On the other hand, if it is possible to provide the tools with which researchers can directly observe phenomena at great depths in the ocean, providing such tools is essential for scientific progresses. This effort will lead to the further development of science and technology.

There would be three viewpoints when discussing the necessity of human occupied submersibles. This is generally common to all fields of science and technology. The first is the contribution to deep sea science (pure science), the second is the application to the industries, and the third is making the tax payers understand. How to balance these three must be the basis for deep sea science and technology policy. The objective of a nation's key science and technology strategy is to maintain the means of securing the national interest. Therefore, it is necessary to maintain and develop the industrial technologies that support this means, and to be able to make people understand who should enjoy the national benefit. Satisfying the individual scientist's intellectual curiosity may be the scientist's motivation for research, but in order to realize this, it is necessary to return the results of research to the nation's people, explain the scientific problems which must be elucidated, and offer a "frontier" which attracts scientists and other technical people. Moreover, the general population must also monitor this science and technology policy.

Japan's deep-submersible HOV, the Shinkai 6500, is capable of reaching the greatest depths of any submersible in the world at the time, but other countries are assiduously developing deep sea research/work technologies that will exceed the capabilities of the this vehicle. Japan must discuss a next-generation deep-submersible HOV while it still enjoys a position of superiority in deep sea technology. Regardless of the difficult challenges we may now face, if we set large goals, the author believes that this country can assemble and train outstanding human resources and this will drive progress in pure science and science and technology. It is hoped that this paper will provide the opportunity to begin debates on the visions that Japan should develop new HOVs in the future.

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Glossary

*1 TAG (Trans-Atlantic Geotraverse): The world's largest hydrothermal mound, located at a depth of 3600m; "black smokers" (a type of hydrothermal vent) approximately 20m high stand on the 200m conical mound.

*2 Deep submergence science: Defined in this report as science constructed on the basis of knowledge obtained by underwater research on the deep sea and seafloor carried out by occupied and unoccupied vehicles.

*3 TIG welding: Tungsten inert gas welding. Welding process using a tungsten electrode with high heat resistance, in which the weld is shielded with an inert gas such as argon, etc. to prevent oxidation of the material. Applied in manual welding of stainless steel and titanium alloys.

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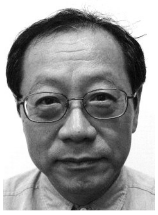

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About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative organizations, with MEXT and other ministries under the general supervision of the Council for Science and Technology Policy, Cabinet Office (CSTP), to develop strategic science and technology policy.

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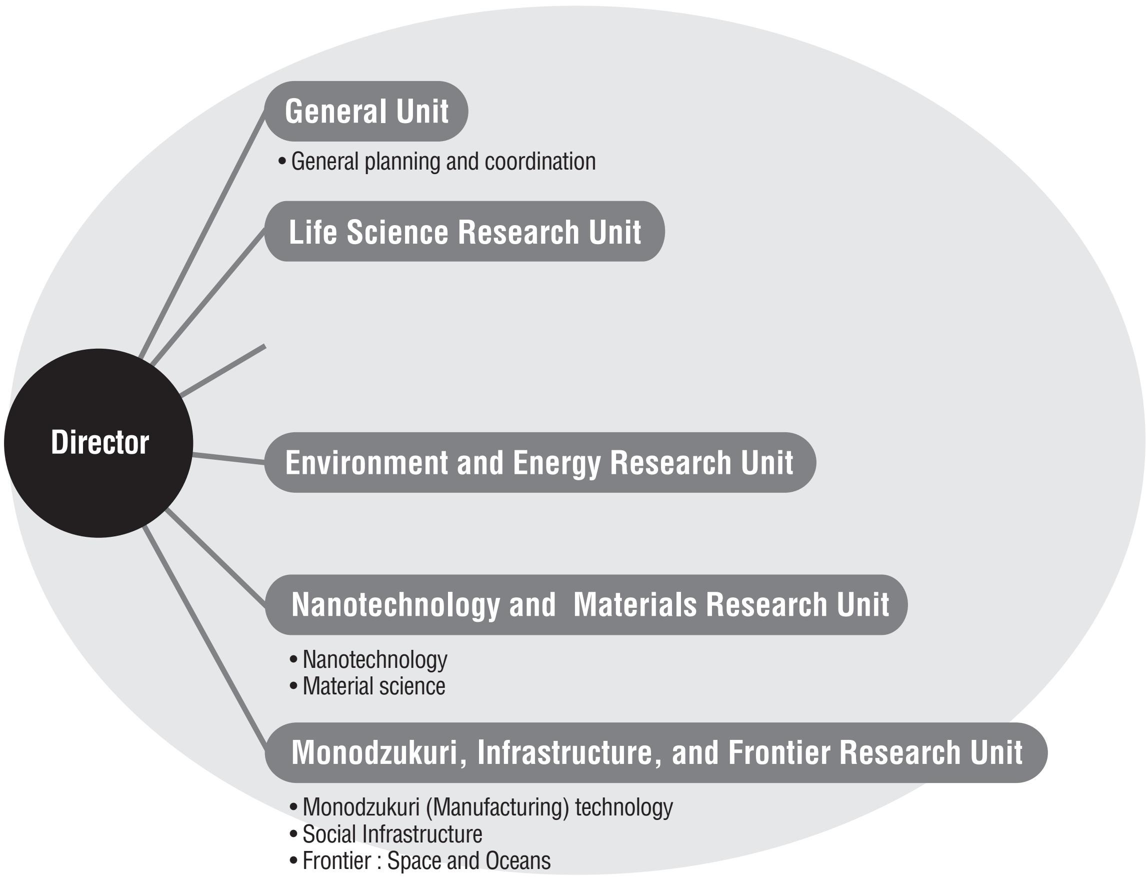
— International Benchmarking of Japan's science and engineering research is also implemented periodically.

— The research results are published as NISTEP report.



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